PHASE I REPORT

Slurry Seal / Micro-Surface Mix Design Procedure
Contract 65A0151

FOR
CALIFORNIA DEPARTMENT OF TRANSPORTATION (CALTRANS)
MATERIALS/INFRASTRUCTURE SECTION

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Slurry seals were developed and used for the first time in Germany, in the late 1920's.(1) At that time, the product consisted of a mixture of very fine aggregates, asphalt binder, and water, and was mixed by introducing the components into a tank outfitted with an agitator. It proved to be a novel approach, a new and promising technique for maintaining road surfaces, and marked the beginning of slurry seal development. However, it was not until the 1960's, with the introduction of improved emulsifiers and continuous flow machines, that real interest was shown in the usage of slurry seal as a maintenance treatment for a wide variety of applications: from residential driveways to public roads, highways, airport runways, parking lots, and a multitude of other paved surfaces.(2)

Micro-surfacing was pioneered also in Germany, in the late 1960's and early 1970's.(1) German scientists were looking for a way to use conventional slurry in thicker applications that could be applied in narrow courses to fill wheel ruts, and not destroy the expensive road striping lines on the autobahns. Micro-surfacing was the result of combining highly selected aggregates and bitumen, and then incorporating special polymers and emulsifiers that allowed the product to remain stable even when applied in multi-stone thicknesses. Micro-surfacing was introduced in the United States in 1980, as a cost-effective way to treat the surface wheel-rutting problem and a variety of other road surface problems.(1)

Despite the widespread use of slurry seals and micro-surfacing, current tests and design methods are primarily empirical and are not related to field performance. There is very limited knowledge on the relationships among certain test parameters, environmental factors, and mix performance in the field. Thus, there is a need to develop new mix design procedures, guidelines, and specifications for slurry seal and micro-surfacing that address performance needs of the owners and users, the design and application needs of the suppliers, and improve the reproducibility of the test methods used for the mix designs. The current International Slurry Seal Association (ISSA) procedures for Slurry Seal Mix Design (A105) and Micro-surfacing (A143) and the corresponding American Society for Testing and Materials (ASTM) Standards D3910 and D6372 have their origin in the 1980's before the widespread use of micro-surfacing and the use of polymer modified emulsions in slurry seals.(3-6) These test methods and design procedures remain in use today because there is no test method or mix design procedure that specifically addresses micro-surfacing and the adequate representation/characterization of its performance indicators. Recent Texas Transportation Institute (TTI) studies documented the problems associated with using the existing methods for micro-surfacing and suggested the development of a comprehensive mix design and analysis procedure.(7) While differences exist between slurry seal and micro-surfacing applications (i.e., traffic volume, application thickness, and curing mechanisms), the similarities of the tests currently used indicate that the two systems must be studied together.

Recognizing the need for more rational design methods for slurry seal and micro-surfacing, the Federal Highway Administration (FHWA) enlisted the California Department of Transportation (Caltrans) to form a pooled fund study to which the following States contributed:

- California
- Delaware
- Georgia
- Illinois
- Kansas
- Maine
- Michigan
- Minnesota
- Missouri
- New Hampshire
- New York
- North Dakota
- Texas
- Vermont

The purpose and scope of this study are described in the following sections.

1.2 OBJECTIVES

The overall goal of this research is to improve the performance of slurry seal and micro-surfacing systems through the development of a rational mix design procedure, guidelines, and specifications.

Phase I of the project has two major components; the first consists of a literature review and a survey of industry and agencies using slurry and micro-surfacing systems; the second part of Phase I deals with the development of a detailed work plan for Phases II and III.

In Phase II, the project team will evaluate existing and potential new test methods, evaluate successful constructability indicators, conduct ruggedness tests on recommended equipment and procedures, and prepare a report that summarizes all the activities undertaken under this task.

In Phase III, the project team will develop guidelines and specifications, a training program, and provide expertise and oversight in the construction of pilot projects intended to validate the recommended design procedures and guidelines. All activities of the study will be documented in a final report.

1.3 PURPOSE OF PHASE I REPORT

The purpose of this report is to summarize the findings and recommendations of the Phase I effort. The report provides the following:

- A literature review of technical documents on the subject at the national and international level.

- The results of three surveys in which questionnaires were sent to industry, State Departments of Transportation (DOTs), and the advisory panel.

- The recommended detailed Work Plans for Phases II and III.

1.4 REFERENCES

1. International Slurry Surfacing Association, Web Page: http: //www.slurry.org. history.

2. Benedict, R.C., New Trends in Slurry Seal Design Methods, *Proceedings of the 23rd Annual Convention of the International Slurry Seal Association*, Orlando, FL, February 3-7, 1985.

3. ISSA Technical Bulletin A105 (Revised) May 2003, Recommended Performance Guidelines for Emulsified Asphalt Slurry Seal, International Slurry Surfacing Association, Annapolis, MD, Web Page: www.slurry.org.

4. ISSA Technical Bulletin A143 (Revised) May 2003, Recommended Performance Guidelines for Micro-Surfacing, International Slurry Surfacing Association, Annapolis, MD, Web Page: www.slurry.org.

5. ASTM Designation D3910-98, Standard Practice for Design, Testing, and Construction of Slurry Seal, *ASTM Book of Standards 1998,* American Society for Testing and Materials, West Conshohocken, PA.

6. ASTM Designation D6372-99a, Standard Practice for Design, Testing, and Construction of Micro-Surfacing, *ASTM Book of Standards 1999,* American Society for Testing and Materials, West Conshohocken, PA.

7. TTI 1289-1, The Evaluation of Micro-Surfacing Mixture Design Procedures and Effects of Material Variation on the Test Responses, Research Report, Texas Transportation Institute, Texas A&M University, College Station, TX, Revised April 1995.

CHAPTER 2 STATE OF THE ART / PRACTICE

Chapter 2 presents the results of the literature review and surveys of agencies and industry to identify the weaknesses in the current mix design systems and develop the framework for improved mix design process. The findings from this effort will form the framework for the improved mix design procedure as well as the test plans for Phases II and III.

2.1 SOURCES OF INFORMATION

Two major sources of information were considered in the literature review:

- Technical papers, research reports, standards, and specifications.
- Responses to questionnaires sent to users/agencies, contractors, and the advisory panel.

The findings from each of these sources are discussed below.

2.1.1 Literature

Although the technical literature on this subject was not expected to be extensive, a significant number of documents were located and reviewed by the team. The documents originate in the United States and abroad (i.e., Europe, South Africa, and Australia) and deal with the various aspects of using slurry seal and micro-surfacing systems in pavements: design, construction, and performance. Following is a list of the documents reviewed:

- ISSA Recommended Performance Guidelines for Slurry Seal Mix Design (A105) and Micro-Surfacing (A143). [1,2]
- ASTM D3910-98 and ASTM D6372-99 Practice for Design, Testing and Construction of Slurry Seal and Micro-Surfacing respectively. [3,4]
- TTI Reports 0-1289-1 & 1289 2-F. [5,6]
- ISSA Design Technical Bulletins. [7]
- ISSA Conference Proceedings. [8-15]
- European Standards EN 12274-1 to 12274-8 Slurry Surfacing Test Methods Part 1 to Part 8. [16-23]
- Technical Guideline: The use of Modified Bituminous Binders in Road Construction. Asphalt Academy c/o Transportek, CSIR. [24]
- Austroads – Guide to the Selection and Use of Bitumen Emulsions. [25]
- Micro-Surfacing Pilot Study 2001, Caltrans. [26]
- Ministry of Transportation, Ontario: Micro Performance Study. [27]
- Friction Evaluation of Slurry Systems in Kansas. [28]
- Pennsylvania Department of Transportation Research Report No. 89-61.[29]
- FHWA Long Term Pavement Performance (LTPP) SPS-3. [30]
- Road Trials of Stone Mastic Asphalt and Other Thin Surfacings, England. [31]

- MnROAD 1999 State Micro-Surfacing Project. [32]
- City of Saskatoon, Saskatchewan, Micro-Surfacing Program. [33]

2.1.2 Agencies, Industry, and Advisory Panel Survey

Following discussions with members of the research team and Caltrans, three surveys were designed and distributed in the Fall of 2003 to the following groups:

- Agencies: Users Survey—Users of the American Association of State Highway Transportation Officials (AASHTO) LISTSERVE link.

- Contractors and Manufacturers: Industry Survey—The United States and international slurry seal and micro-surfacing industry.

- Advisory Panel Survey: Advisory Panel contractors.

The surveys were designed to identify key aspects of the use of slurry seal and micro-surfacing systems, as well as limitations, concerns, and expectations that respondents had with these systems. The blank surveys can be found in Appendix A. The original responses to the surveys are summarized in Appendix B. In Appendix C, the surveys are reviewed and abstracted for clearer analysis. The surveys are summarized in Survey Results later in this chapter.

The contents of this chapter, the conclusions, and recommendations, are based on the review of existing literature on slurry seal and micro-surfacing systems and the responses to questionnaires received from agencies and contractors that use these systems.

> **NOTE: The Questionnaires were not designed to be analyzed using any particular analysis technique, but instead were intended to obtain a "snapshot " of existing practices. The results of the three surveys are from a very limited sample; therefore, the data is not to be considered irrefutable. For example, the project team is aware of slurry projects that have been in service more than 15 years, although none reported in this survey were listed with a service life of more than 3-5 years.**

2.2 SURVEY RESULTS

Although the three surveys addressed different segments of the slurry seal and micro-surfacing industry (i.e., agencies, industry, advisory panel), the respondents were encouraged to answer any of the three questionnaires. Although most respondents returned only one of the questionnaires, a few of them filled out both the industry and agency questionnaires.

2.2.1 Agency Surveys

The agency survey was sent to all States and Canadian provinces. The following agencies responded to the survey prior to the end of 2003:

- Alberta Transportation
- Arkansas Highway Transportation Department (HTD)
- British Columbia Ministry of Transportation
- Illinois DOT
- Indiana DOT
- Kansas DOT
- Kentucky DOT
- LaSalle County Highway Department, Illinois
- Maine DOT
- Maryland SHA
- Minnesota DOT
- Minnesota DOT, St. Cloud District
- Missouri DOT
- Montana DOT
- New Hampshire DOT
- New Jersey DOT
- Nova Scotia Transportation and Public Works
- Virginia DOT
- Wisconsin DOT
- Wyoming DOT
- Urbana, City of, Illinois

Of the 21 respondents, 71 percent are currently using slurry seals and/or micro-surfacing systems, and 76 percent plan to use it in the future. The 29 percent not using these treatments either do not have experience with these materials or they have experienced past short-term failures.

Averaging agency usage results in the following numbers: 944,000 square yards of micro-surfacing were placed in 2001; 663,000 in 2002; and 717,000 in 2003. The standard deviation was about 60,000 square yards in all three years. The data on slurry seal use is very limited. According to these figures, the use of micro-surfacing did not decrease or increase; rather, it remained relatively constant at an average of nearly 700,000 square yards per year, per agency.

All those who are currently using these systems expect to continue using them in the future. The primary benefits they cite for continuing the use of these systems are, in the order of frequency:

- Extend the pavement life (most frequent)
- Improve skid resistance
- Cost effectiveness

- Good performance
- Rut filling (least frequent)

With regard to the observed and expected service life of slurry seals and micro-surfacing, the respondents observed and expect service lives of three to five years for slurry seal and five to seven years for micro-surfacing (on average). It is generally recognized that the life of the treatment is a function of traffic levels, workmanship, and the condition of the existing pavement.

Very few responses were received regarding the problems encountered with surface seals during and after construction. For micro-surfacing however, various problems were identified and are listed here, in the order of frequency:

- During construction:
  - Workmanship (most frequent)
  - Cure time related
  - Control of mixing (correct amount/proportions of water, emulsion, aggregate, lime)
  - Other, less frequent (traffic control, emulsion control, aggregate gradation, set time related)

- After construction:
  - Reflective cracking (most frequent)
  - Rutting
  - Raveling
  - Delamination
  - Wear
  - Other, less frequent (potholing, bubbling surface in hot weather, flushing, snow plow blade damage)

Note that the most frequent short-term problems (during construction) are related to workmanship. Again, it appears that the skills of, or techniques used by, the construction crew are crucial to the success of the project. On the other hand, it is important to note that the most frequent long-term problems are reflective cracking and rutting, which are most likely not related to the mix-design or construction process but rather the result of inappropriate project selection.

The last question on the agency questionnaire dealt with quality assurance testing performed by the agencies. Of the 17 agencies that responded to this particular question, only 60 percent have some form of quality assurance program. The most frequent tests performed by the agencies are independent testing of the aggregate (gradation) and the emulsion prior to construction. Other tests included are asphalt content and moisture. Less frequent tests include: sand equivalent test for the aggregate, placement of a test strip before construction, contractor pre-qualification, visual acceptance in the field, warranted specification and checking the thickness from field cores.

Note that none of the tests mentioned are performed on the mix, except for the placement of a test strip and the visual acceptance in the field. However, it would be desirable to have a field test to evaluate the mix and relate the results of this test to measures of performance.

The final comments of the agency questionnaire re-iterate some of the problems already mentioned with slurry seal and micro-surfacing and express the hope that this study will address these problems and provide a more robust and practical design method.

2.2.2 Industry Surveys

A total of 21 industry participants and agencies responded to the industry survey. Those responding include the following:

- Al Debras Asphalt Emulsion Co.
- California Pavement Maintenance
- Dansk Ovberfladebehandling I/S
- E.J. Breneman L.P.
- Ergon
- Fulton Hogan Ltd
- Higgins Contractors Ltd
- International Technology Group
- Koch Materials Company
- Koch Pavement Solutions
- Lafarge Asphalt Engineering
- Maryland SHA
- Nova Scotia Transportation and Public Works
- Paragon Technical Services
- Pavimentos Coservacion y Microsuperficie SA de CV
- Pioneer Road Services Pty Ltd
- PRI Asphalt Technologies, Inc.
- Strawser Inc.
- TIPCO Asphalt Public Company Limited
- Vestal Asphalt, Inc.
- Viking Construction, Inc.

More than 76 percent (16 of 21) of the respondents perform their own mix design for slurry seals and/or micro-surfacing. Of these, the majority (12 of 16) use the ISSA procedures, as they are, or with minor modifications. A limited number of respondents (3 of the 16) use the local DOT specification, and only 1 of 16 uses the ASTM methods.

Of those who do not perform mix designs, either they do not have the necessary laboratory equipment or the design is carried out by the contractor or the emulsion supplier. Very few survey participants responded to the question regarding the design method they plan to use in the future.

Of those performing their own designs, 7 of 16 use the ISSA method without any modifications. Of the remaining respondents, five use the ISSA method with minor modifications. These modifications generally add or eliminate tests from the original ISSA method according to local agency requirements. Only one respondent uses the ISSA with a major modification, requiring the use of a range of conditioning methods (temperature/humidity). Two respondents did not know how different their design method was from the ISSA procedure.

When asked if there are test methods and/or procedures that need to be revised or eliminated, 43 percent of the respondents replied in the affirmative. Generally, the industry is concerned with the repeatability of all the tests and their ability to predict performance.

According to the respondents, the tests that they consider to relate to the field performance of the mix in the construction stage are the Modified Cohesion Test (ISSA TB 139) and the Trial Mix Procedure (ISSA TB 113). Other tests are mentioned but less frequently.

In terms of long-term field performance of the mix, the survey results suggest the Wet-Track Abrasion Test (WTAT), ISSA TB 100, and its six-day soak variant as the best candidate. Following the WTAT, in order of importance, the next most reliable long-term field performance tests include the Loaded Wheel Test (LWT), ISSA TB 109, and the Schulze-Breuer and Ruck Procedure, ISSA TB 144. Other tests are mentioned, but less frequently.

The most frequent complaints industry receives from their customers deal with the initial appearance of the surface treatment and with issues of workmanship. Other frequent complaints include the complexity of the design process, the rough surface/ride, and the fact that the mix is tender in hot weather conditions.

During field operations, most frequently the respondents try to control the amount of water added to the mix. Other parameters they suggest that need to be controlled include mix time, set time, good workmanship, and mix proportions. However, industry would allow for variations in mix proportions as dictated by the prevailing weather conditions and changes in the aggregate source and/or emulsion type.

Finally, the respondents expressed their concerns with the repeatability of the current test methods and the feasibility of a new and more complex design method. They recognize the need for a test method that will take into account a range of possible environmental conditions. They also recognize their need for technical advice and the education of clients on the proper use of slurry seals and micro-surfacing.

2.2.3 Advisory Panel Surveys

Out of a total of 14 members, only four advisory panel members responded to this survey. They include the following:

- Ergon A&E
- MeadWestvaco Corporation
- Pioneer Road Services Pty Ltd
- Strawser, Inc.

According to the survey results, the emulsion supplier generally performs the design for both slurry seals and micro-surfacing. One of the four respondents relies on the use of a private testing laboratory.

The primary area of complaint from the customers of the advisory panel members varied from one panel member to another—no common area of concern was identified.

For two of four respondents, the mix designs provided to them do satisfy their requirements in terms of being able to mix, place, and finish the system. The other two respondents did not answer this question.

Three of the four respondents adjust the mix design in the field. Adjustments are made to the water, mineral filler, and emulsion contents. Generally, these adjustments are within the limits specified in the design. The primary reasons for adjusting the design are to control workability, mix time, and cure time of the mix as needed in the field.

Several difficulties in reproducing the laboratory mix design in the field have been reported, which include:

- The amount of mineral filler required is sometimes as low as 0.5 percent and some machines have a hard time providing consistent flow at this low level.

- Stockpile moisture and amount of fines in the aggregate can be highly variable.

- A nighttime micro-surfacing project that was exposed to heavy traffic and rain very soon after application failed. The mix design did not identify the sensitivity to moisture during the transition from early rolling traffic cohesion to final cure and set.

Finally, the respondents identified several issues worth mentioning:

- The rather vague nature of the current design guidelines. An example is the optimum emulsion content for which the typical design window is too wide, sometimes as wide as 6.0 percent but usually 2.0 to 4.0 percent.

- Problems caused by the variability (ratio and quantity) of mix components in the field and changes in asphalt or aggregate sources.

- Other problems arising from changes in the ratio of components in the mix or significant changes in the environmental conditions.

The experience of the construction crew is one of the major factors affecting the success of a project.

2.3 EXTENT OF USE WORLDWIDE

Since 1977, the ISSA has held a World Congress every five years, usually outside the United States. These meetings are intended to encourage Association members from around the world to share their experiences with slurry seal and micro-surfacing systems. At the World Congress in Paris, 1997, the first slurry seal and micro-surfacing usage report was presented.

The last such Congress was held in Berlin, Germany, in 2002. Table 2-1 provides the information reported during that meeting for the year 2000. It remains the latest data available to-date on worldwide usage of slurry seal and micro-surfacing systems. The data does not break out the United States from North America, but it should be noted that the majority of the work was done in the United States. In summary, the worldwide usage reported for slurry seal was 12,073,231 tons and the amount of micro-surfacing was 1,964,556 tons.

TABLE 2-1 Worldwide Slurry Seal and Micro-Surfacing System Usage in 2000

COUNTRY	SURFACING SYSTEM	
	SLURRY SEAL TONNAGE	**MICRO-SURFACE TONNAGE**
Africa	26,400	31,950
Middle East	121,000	22,000
Europe	213,950	958,958
Pacific Rim	349,800	75,900
Latin America	94,600	16,500
North America	1,158,806	967,923
TOTAL TONNAGE	1,964,556	2,073,231

2.4 CURRENT MIX DESIGN PROCEDURES

There are several mix design procedures currently available. Those included for detailed discussion in this report are the ISSA Technical Bulletin (TB) guidelines and ASTM designated standards/specifications. Of these, the most commonly used worldwide are ISSA Guidelines A105 and A143 and ASTM Standards D3190 and D6372.[1-4] State agencies, such as the Texas Department of Transportation (TxDOT) also have initiated slurry seal and micro-surfacing research projects on their highway networks and developed their own standards and guidelines for design. The European Union has a similar set of standards (norms) on the design and use of slurry seal and micro-surfacing. Germany, France, United Kingdom, and South Africa have had significant experience with slurry seal and micro-surfacing systems, and have developed specific guidelines for their use.

All the current methods of design are described in this section, with emphasis on the ISSA and ASTM design methods that are the most widely accepted and used.

2.4.1 ISSA Design Method for Slurry Seal, ISSA TB A105[1]

The ISSA method, revised May 2003, is the most widely used procedure for the design of slurry seal in the United States and around the world. Note that not all the tests included in the ISSA TB A105 are required; some tests can be eliminated based on the experience of the designer with the materials involved in the slurry seal system.

The components of the mix are tested first. The aggregate has to conform to one of the three gradations given in Table 2-2.

TABLE 2-2 ASTM Types I, II, and III Gradations

Sieve Size		Percent Passing by Weight			Stockpile Tolerance, %
in	mm	Type I	Type II	Type III	
3/8	9.500	100	100	100	
No. 4	4.750	100	90-100	70-90	+/- 5
No. 8	2.360	90-100	65-90	45-70	+/- 5
No. 16	1.180	65-90	45-70	28-50	+/- 5
No. 30	0.600	40-60	30-50	19-34	+/- 5
No. 50	0.300	25-42	18-30	12-25	+/- 4
No. 100	0.150	15-30	10-21	7-18	+/- 3
No. 200	0.075	10-20	5-15	5-15	+/- 2

In addition, the aggregate has to pass the following tests/criteria:

- Sand Equivalent [34]: > 45
- Soundness [35]: < 15 percent using Na_2SO_4 or < 25 percent using $MgSO_4$
- Abrasion Resistance [36] : < 35 percent

The mineral filler is selected to meet the requirements of ASTM D242.[29]

The ISSA procedure gives many choices for the asphalt emulsion. However, they are to conform Grades: SS-1, SS-1h, CSS-1, CSS-1h, CQS-1h, Quick Set Mixing Grade as specified in ASTM D977 and D2397 with the caveat that the cement mixing test can be waived.[38,39] In addition, the asphalt emulsion must have a minimum of 60 percent residue after distillation using ASTM D244.[40] The emulsion residue must have a penetration value of 40 to 90, which is 0.1 mm at 25°C (77°F).

Following are the mix tests recommended by the ISSA procedure.

2.4.1.1 Consistency Test, ISSA TB 106

This test is used to determine the optimum mix proportions (proper ratio of aggregate, filler, water, and emulsion) as related to consistency for pavement surface placement.[41] Several mixes are made using dried aggregate and various ratios of mineral filler, asphalt emulsion, and water. The standard does not specify the number of samples or the amount of variation in each component. The result of the test is a measurement of flow of the mix on a plate when poured from a standard mold. For a mix to pass the consistency test, the flow should be between 2 cm and 3 cm.[41

2.4.1.2 Modified Cohesion Test, ISSA TB 139

A cohesion-testing device (see Figure 2.1) is used to measure cohesion at the interface between a rotating neoprene cylinder and the slurry seal test specimen, at different times after mixing and setting of slurry seal test specimens.[42] The test specimens are disk shaped with dimensions of 6 mm (0.24 in) thick and 60 mm (2.36 in) in diameter. A pressure of 200 kPa (29 psi) is applied through the neoprene foot while the cylinder is rotated 90 to 120 degrees. The torque needed to rotate the cylinder in contact with the specimen is measured with a torque wrench at 30-minute intervals. Note that the test is run on specimens that reached initial set. Set time is defined as the lapsed time after casting when a slurry system may not be remixed into a homogenous slurry. A plot of torque versus time is developed and used to classify the system in terms of set time and traffic time. The classification chart from the ISSA TB 139 is reproduced in Figure 2-2.

As illustrated in Figure 2-2, set time occurs at a torque level of 12 kg-cm. Early rolling traffic time occurs at a torque level of 20 kg-cm. A quick set system reaches a 12 to 13-kg-cm cohesion torque within 30 minutes and a 20 to 21-kg-cm cohesion torque within 60 minutes. The test is used to identify quick-set/quick-traffic systems.

2.4.1.3 Loaded Wheel Test, ISSA TB 109

The LWT is recommended for heavy traffic areas only.[43] The mixture is compacted by means of a loaded, rubber tired, reciprocating wheel. The first parameter measured is the tack point (the point at which an audible tackiness and visible shine are noted). However, the tack point is not used as criteria for design. The other parameter measured is the sand adhesion, which is an indirect measure of the amount of excess asphalt in the mix. For a mix design to be acceptable, the LWT sand adhesion has to be less than 538 g/m^2 (50 g/ft^2). Note that the sand adhesion value is a function of the number of cycles (usually 1,000 cycles conditioning and 100 for the test) and load (usually 57 kg [125 lbs] plus the weight of the frame).

2.4.1.4 Wet Stripping Tests, ISSA TB 114

This test is used to check the compatibility of the slurry seal system with the aggregate.[44] An oven cured sample of the slurry seal system is immersed in boiling water for three minutes. After boiling, the sample is dried, examined for uncoated areas, and an estimate is made of the area of aggregate remaining coated with asphalt. The mix passes the compatibility requirement if the percent area coated with aggregate after boiling water immersion is higher than 90.

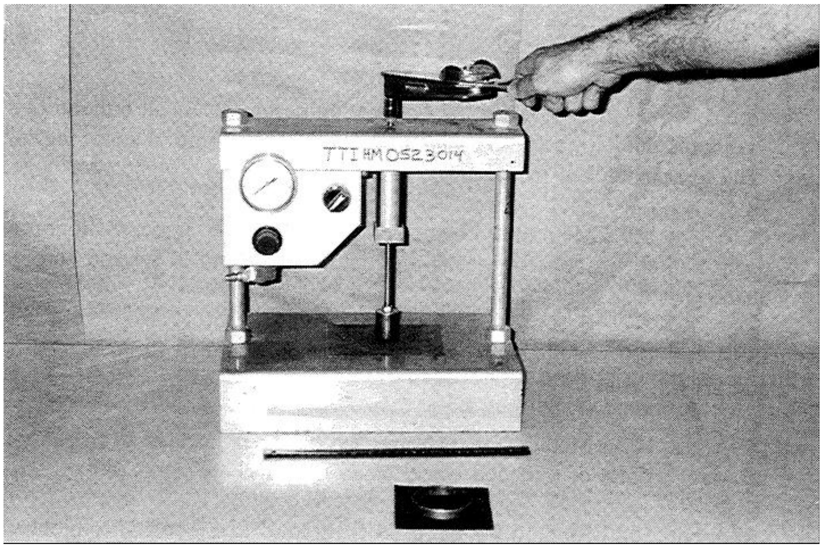

FIGURE 2-1 Cohesion tester

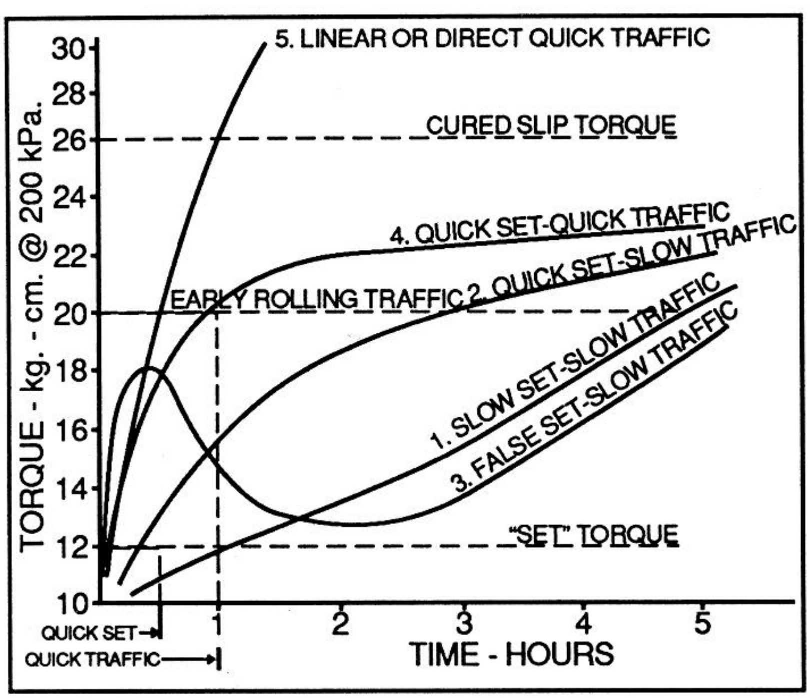

FIGURE 2-2 Classification chart [42]

2.4.1.5 Wet-Track Abrasion Loss Test, ISSA TB 100

The WTAT method measures the wearing qualities of slurry seal under wet abrasion conditions.[45] The test specimens are disk-shaped, 6 mm (0.25 in) thick, and 279 mm (11 in) in diameter. After initial set of the mix, the specimen is dried to constant weight in an oven. The cured slurry is placed in a water bath for one hour and then mechanically abraded under water with a rubber hose for five minutes. The abraded specimen is washed free of debris, dried in the oven, and weighed. The result of the test is the loss in weight of the specimen expressed in grams per square meter (or square foot) and is reported as the wear value, also denoted as WTAT loss. For a design to be accepted, the WTAT loss should be less than 807 g/m^2 ($75 g/ft^2$).

Again, in the ISSA mix design, not all tests are required and designers are permitted to eliminate tests based on their past experience with the material.

2.4.2 ASTM Design Method for Slurry Seal, ASTM D3910-98[2]

The first paragraph of ASTM D3910-98, the "Scope," states that these design practices are: "…written as a guide and should be used as such. End-use specifications should be adapted to conform to job and user requirements." This statement indicates that the successful placement and subsequent field performance of a mix passing all design criteria in the laboratory cannot be guaranteed. The designer has the freedom and responsibility to make adjustments to the design on a case-by-case basis. This is one of the major limitations common to all current micro-surfacing and slurry seal systems design methods.

Figure 2-3 illustrates the primary steps of the ASTM design process for slurry seal. As illustrated, the mix components (i.e., aggregate, filler, and asphalt emulsion) are selected first. Three aggregate gradations are recommended for the slurry, depending on the intended use or performance requirements of the system. The three gradations are commonly referred to as Types I, II and III, with Type I being the finer (i.e., least resistant to traffic loads) and Type III being the coarser (i.e., more appropriate for high traffic loads and volume). The three gradations are similar to those specified in the ISSA procedure that were given in Table 2-2. Note that Type II and III gradations are identical to Types II and III recommended for micro-surfacing systems. Stockpile tolerances are not specified in the ASTM method.

In addition, the selected aggregate has to satisfy:

- Quality requirements of ASTM Specification D1073.[46]
- Sand equivalent not less than 45.
- Percent of smooth-textured sand of less than 1.25 percent water absorption less than 50 percent of the total combined aggregate.

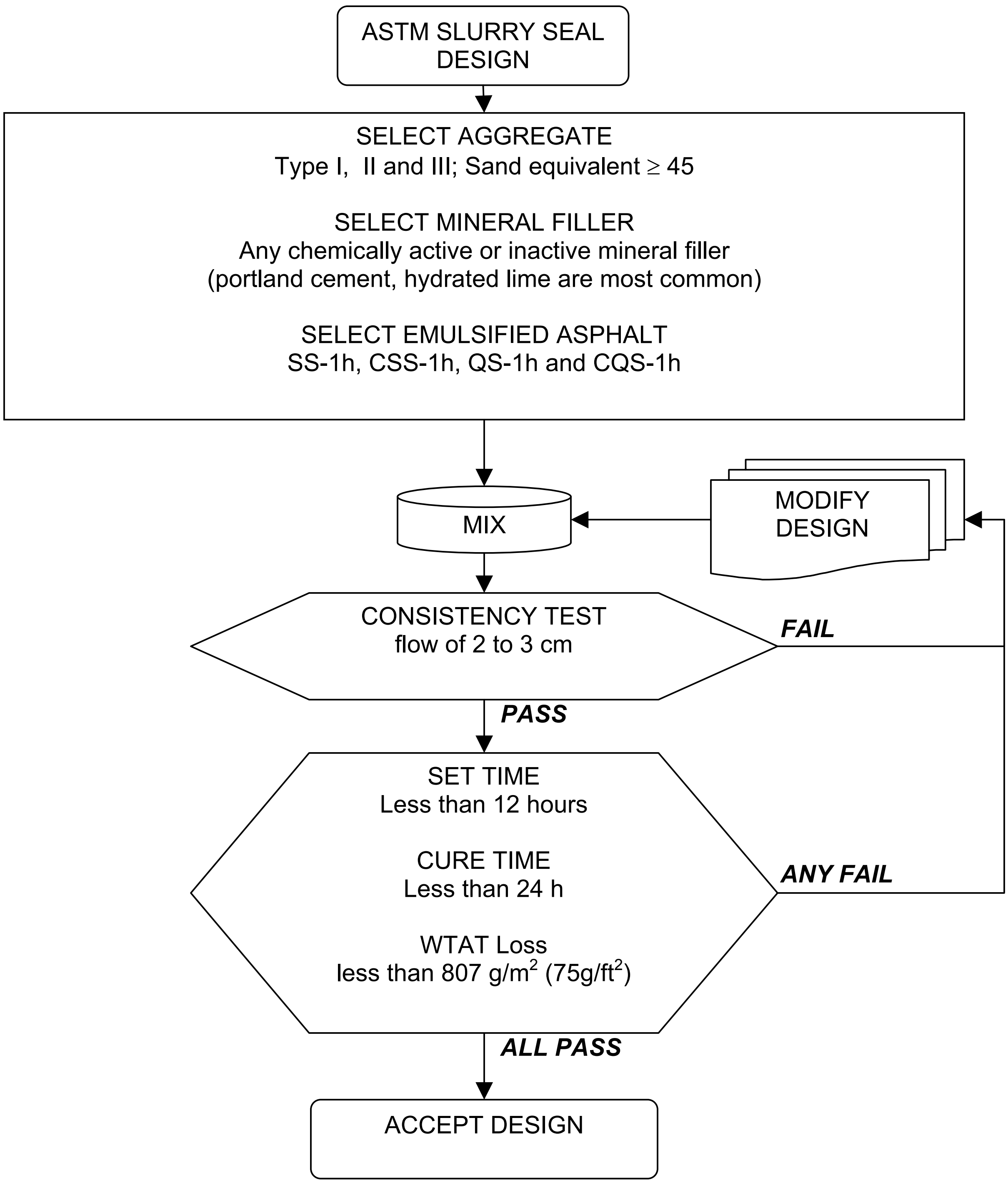

FIGURE 2-3 ASTM design method for slurry seal

Mineral fillers, both chemically active and inactive, shall conform to ASTM D242. The specification is further described later in this chapter under Laboratory Tests.

It is suggested that the asphalt emulsion conform to Grade SS-1h of ASTM D977 for emulsified asphalt or Grade CSS-1h of ASTM D2397 for cationic emulsified asphalt. Quick-Set emulsified asphalts can be used and should conform with ASTM D977 and D2397, with the exception that test requirements for cement mixing and storage stability shall not apply.

In the second phase of the design process, the selected components of the slurry seal system are mixed together, trial samples are made, and the samples then are subjected to testing. However, an important limitation is that the standard is not specific about the number of samples needed. The four tests recommended by the standard are discussed below.

2.4.2.1 Consistency Test, ISSA TB 106

This test is described in Section 2.4.1.1. For a mix to pass the consistency test, the flow should be between 2 cm and 3 cm.

2.4.2.2 Set Time Test

This method is used on mixes that pass the consistency test to determine the time required for the slurry mixture to reach initial set. The slurry is poured on a flat surface, screeded to 6-mm (0.25 in) thickness, and blotted with a white paper towel at several time intervals. The time required to obtain a stain-free blot is recorded as the set time. A mix is accepted if the initial set time is less than 12 hours.

2.4.2.3 Cure Time Test, ISSA TB 139

Similar to the cohesion test used in the ISSA design method for slurry seals, a cohesion-testing device is used to measure cohesion at the interface between a rotating neoprene cylinder and the test specimen.(42) The time required to reach a constant maximum torque or until the neoprene foot rides freely over the slurry mat without any aggregate particles being dislodged, is recorded as the cure time. The design is acceptable if the cure time is less than 24 hours.

2.4.2.4 Wet Track Abrasion Test, ISSA TB 100

The WTAT is described in Section 2.4.1.5. For a design to be accepted, the WTAT loss should be less than 807 g/m^2 (75g/ft^2).

If the mix passes all four tests and the components satisfy the requirements of the standard, the design is accepted.

2.4.3 ISSA Design Method for Micro-Surfacing, ISSA TB A143[2]

ISSA A143, revised May 2003, is the most widely used method for the design of micro-surfacing systems in United States and around the world. Not all the tests included in the procedure are required; some tests can be eliminated based on the experience of the designer with the materials involved in the micro-surfacing system.

Similar to the methods used for slurry seals, the components of the mix are tested first. The aggregate has to conform to the Type II or III gradation given earlier in Table 2-2. The same stockpile tolerances apply. In addition, the aggregate has to meet the following criteria:

- Sand Equivalent: > 65
- Soundness: < 15 percent using Na_2SO_4 or < 25 percent using $MgSO_4$
- Abrasion Resistance: < 30.0 percent
-

The mineral filler can be any recognized brand of non-air entrained portland cement or hydrated lime.

The binder is normally a quick traffic, polymer modified, asphalt emulsion conforming to the requirements of ASTM D2397 for CSS-1h (the cement mixing test is waived). In addition, the asphalt emulsion must have a minimum of 62 percent residue after distillation using ASTM D244.[38] The emulsion residue has to meet the following criteria:

- Softening Point: 135°F (57°C) minimum [47]
- Penetration Value: 40 to 90 (0.1 mm) at 25°C (77°F) [39]
- Kinematic Viscosity @ 275°F (135°C): 650 cSt/sec minimum [48]

Following are the mix tests recommended for use in the ISSA procedure. In general the tests are identical to those used for slurry seals.

2.4.3.1 Modified Cohesion Test, ISSA TB 139

The test is discussed in Section 2.4.1.2. The mix should classify as a quick set system (i.e., cohesion torque > 12 kg-cm @ 30 minutes and > 20 kg-cm @ 60 minutes).

2.4.3.2 Loaded Wheel Test, ISSA TB 109

The LWT is described in Section 2.4.1.3. For a mix design to be acceptable, the LWT sand adhesion has to be less than 538 g/m^2 (50 g/ft^2). Note that the sand adhesion value is a function of the number of cycles (usually 1,000 cycles conditioning and 100 for the test) and load (usually 57 kg [125 lbs] plus the weight of the frame).

2.4.3.3 Wet Stripping Tests, ISSA TB 114

Described in Section 2.4.1.4, a mix passes the compatibility requirement if the percent area coated with aggregate is higher than 90 percent.

2.4.3.4 Wet-Track Abrasion Loss Test, ISSA TB 100

The test is described in Section 2.4.1.5. For a mix design to be accepted, the WTAT loss should be less than 807 g/m^2 (75g/ft^2) for 6-day soaked samples and less than 538 g/m^2 (50 g/ft^2) for 1-hour soaked samples.

2.4.3.5 Lateral Displacement Test, ISSA TB 147

Because micro-surfacing can be used for filling ruts, there are three test procedures used to measure the amount of compaction or displacement characteristics of micro-surfacing under simulated rolling traffic compaction.

- The Loaded Wheel Test
- The Modified British Wheel Tracking Test
- The Lai Modified Loaded Wheel Test

All three tests are presented in the ISSA TB 147.[(49)] However, it is not clear whether the designer can use only one of the three tests or if all three tests are required. A brief description of each test is presented below:

- The *Loaded Wheel Test* is described in Section 2.4.1.3. In addition to the regular procedure, the width and height of the specimen are measured (in the wheel path) before and after 1,000 cycles of LWT compaction, and the vertical and lateral displacement are calculated. Density (before and after compaction) is also to be calculated. It has been found that unconfined, vertical deformations that exceed 10 percent are not satisfactory for uncompacted, multi-layer applications.

- The *Modified British Wheel Tracking Test* was originally developed to test the resistance of hot mix asphalt to rutting. Similar to the LWT, the load is applied through a wheel. However, in the British test, the wheel is larger (203 mm [8 in] diameter), and stationary; and the test sample is moved back and forth under tire pressure. The penetration of the wheel into the mix is measured and plotted versus time. The rate of loaded wheel penetration is calculated and reported in mm/hr. The test is run at 45ºC (113ºF) and the load on the wheel is approximately half that used in the LWT loading, 11.4 kg/cm (63.8 lbs/in) of tire width. For uncompacted mixes, the test is run for 1 hour or 2,520 cycles. For pre-compacted samples, the test is run for 45 minutes or 1,890 cycles. Vertical displacements less than 10 percent and lateral displacements less than 5 percent are considered satisfactory for multi-layer applications. A compacted specific gravity less than 2.10 is acceptable.

- The *Lai Modified Loaded Wheel Test* is a modification of the LWT that uses a variably pressured air hose between the loading wheel and the test specimen, and is run at a temperature of 40.5ºC (105ºF). The pressure in the hose is 689 kPa (100 psi). Rut depth is measured after 1,000 cycles of loading. Not enough work has yet been reported to categorize the results.

2.4.3.6 Classification Test, ISSA TB 144

This test is used to determine the relative compatibility between the aggregate filler of a specific gradation and emulsified asphalt residue.(50) The end result is a grading value, or rating system, for adhesion (in percent coated), abrasion loss (in grams lost), and high temperature cohesion characteristics (absorption in grams absorbed and integrity in percent retained mass) of a specified filler-bitumen combination for comparison with test values of reference combinations. The classification system is given in Table 2-3. For a design to be acceptable, the mix must achieve 11 grade points minimum (i.e., AAA or AAB).

TABLE 2-3 Compatibility Classification System(50)

Grade Rating Each Test	Point Rating Each Test	Abrasion Loss (Grams)	Adhesion 30 Min Boil (% Coated)	Integrity 30 Min Boil (% Retained)
A	4	0 – 0.7	90 – 100	90 – 100
B	3	0.7 – 1.0	75 – 90	75 – 90
C	2	1.0 – 1.3	50 – 75	50 – 75
D	1	1.3 – 2.0	10 – 50	10 – 50
E	0	>2.0	0	0

2.4.3.7 Mix Time Test, ISSA TB 113

With all mix ingredients at room temperature, trial specimens are mixed manually in disposable cups.(51) The specimens are visually examined for: tackiness, shininess, fines floatation, and internal adhesion. Any observable problems are corrected by altering the design and repeating the experiment until the problems are eliminated.

Again, in the ISSA procedure not all tests are required and designers are allowed to eliminate tests based on their past experience with the material.

2.2.4 ASTM Design Method for Micro-Surfacing: ASTM D 6372-99a(4)

The ASTM design method for micro-surfacing is similar to the ASTM method used for the design of slurry seals with few exceptions, as illustrated in Figure 2-4.

The aggregate should be totally crushed with 100 percent of the parent aggregate being larger than the largest stone in the gradation to be used. The grading requirements are identical to those given in Table 2-2 for slurry seals with the exception of the Type I gradation, which is not recommended for micro-surfacing and a note that tolerances are not specified in the ASTM method. The aggregate has to pass the following tests/criteria:

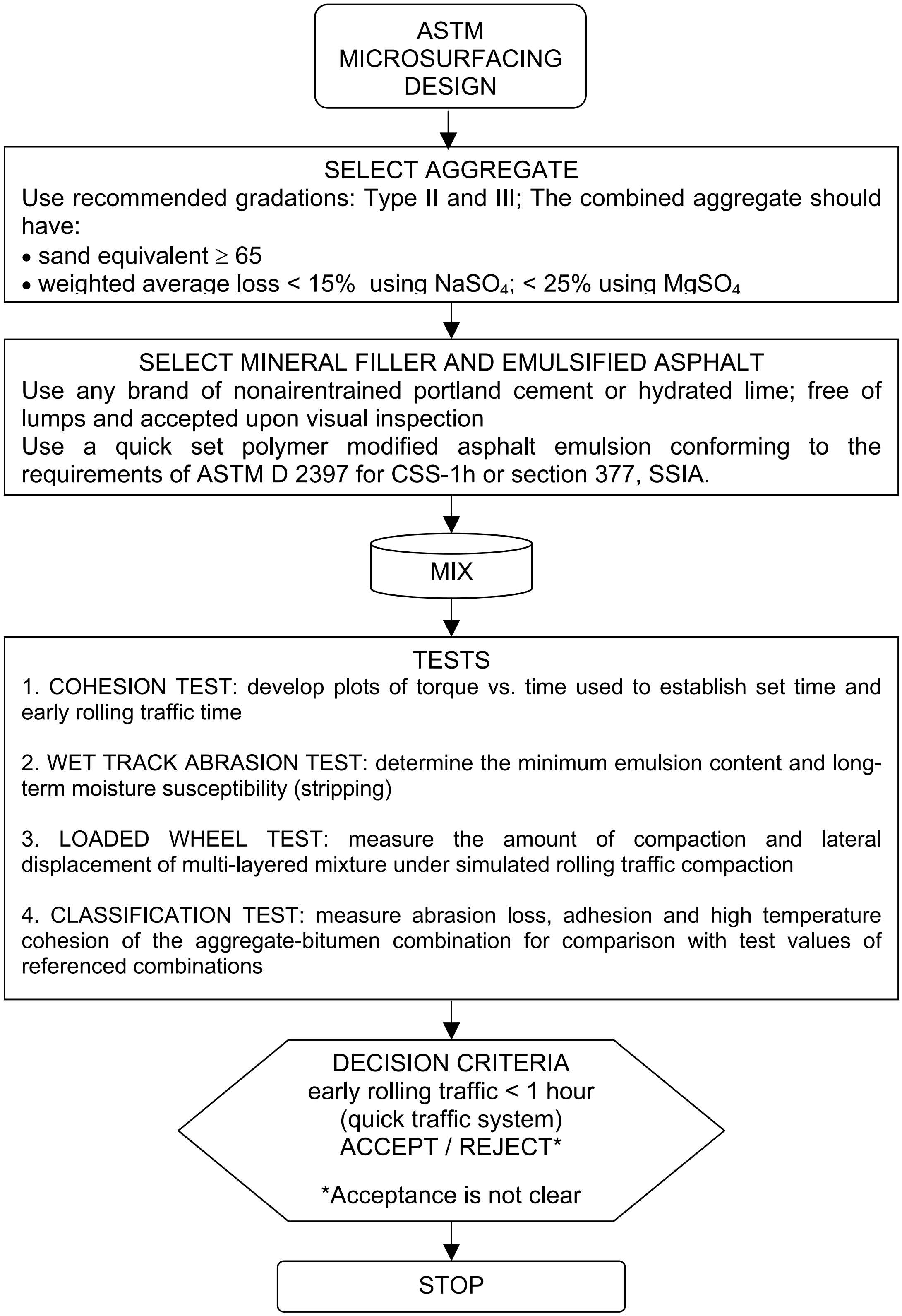

FIGURE 2-4 ASTM design method for micro-surfacing

- Sand Equivalent: > 65
- Soundness: < 15 percent using Na_2SO_4 or < 25 percent using $MgSO_4$
- Abrasion Resistance: < 30 percent

The mineral filler can be any recognized brand of non-air entrained portland cement or hydrated lime.

The binder should be a quick set, polymer modified, asphalt emulsion conforming to the requirements of ASTM D2397, with the cement mixing and the five-day settlement tests waived.

The mix tests recommended by the ASTM procedure are discussed below.

2.4.4.1 Modified Cohesion Test, ISSA TB 139

This is discussed in Section 2.4.1.2. The mix design is considered acceptable if it conforms to the specifications for a quick traffic system (see Figure 2-3).

2.4.4.2 Wet-Track Abrasion Loss Test, ISSA TB 100

The WTAT is described in Section 2.4.1.5. For a design to be accepted, the WTAT loss should be less than 807 g/m^2 (75g/ft^2).

2.4.4.3 Loaded Wheel Test, ISSA TB 109

The LWT was described in Section 2.4.1.3. For a mix design to be acceptable, the LWT sand adhesion must be less than 538 g/m^2 (50 g/ft^2). Note that the sand adhesion value is a function of the number of cycles (usually 1,000 cycles conditioning and 100 for the test) and load (usually 57 kg [125 lbf] plus the weight of the frame).

2.4.4.4 Classification Test, ISSA TB 144

As described in Section 2.4.3.6, this test is used to determine the relative compatibility between aggregate filler of specific gradation and emulsified asphalt residue. Although no guidelines are given on what is acceptable, it seems reasonable to assume that mixes graded A or B for each test are acceptable. (A or B indicates a very high score when the results of all three tests are added together.)

2.4.5 TTI Design Method for Micro-Surfacing, TTI 1289(5)

This method was developed at the Texas Transportation Institute in 1994 after an evaluation of the repeatability of the conventional mix tests recommended by the ISSA guidelines for the design of micro-surfacing.(6)

The TTI study found that the reliability of determining mixture quality of micro-surfacing with the ISSA procedure was questionable. As a result, a new mix design method was developed. In this method, the components of the mix are tested first. The aggregate has to conform to a Grade 1 or Grade 2 gradation, as given in Table 2-4. Note that the gradations in Table 2-4 are somewhat different (they are finer for sieve sizes $^3/_8$ in to #16) than those used in the ASTM and ISSA methods.

In addition, the aggregate must meet the following criteria:

- Sand Equivalent: > 70
- Soundness: < 25 percent using $MgSO_4$

TABLE 2-4 TTI Method Aggregate Gradations

Sieve Size		Percent Passing by Weight		Allowable Tolerance, %
in	mm	Grade 1	Grade 2	
3/8	9.500	100	100	+/- 5
No. 4	4.750	98-100	99-100	+/- 5
No. 8	2.360	75-90	45-65	+/- 5
No. 16	1.180	50-75	25-46	+/- 5
No. 30	0.600	30-50	15-35	+/- 3
No. 50	0.300	18-35	10-25	+/- 3
No. 100	0.150	10-21	7-18	+/- 3
No. 200	0.075	5-15	5-15	+/- 2

The mineral filler can be any recognized brand of non-airentrained portland cement or hydrated lime.

The asphalt emulsion is normally a cationic, slow setting, polymer modified emulsion, designated as CSS-1P. In addition, the emulsion should meet the following criteria:

- Minimum 3 percent polymer by weight
- Viscosity, Saybolt Furol at 25ºC (77ºF): 20 to100 seconds
- Storage stability test, one day: 1 percent maximum
- Particle charge test: positive
- Sieve test: 0.1 percent maximum
- Oil distillate, by volume of emulsion: 0.5 percent maximum
- Residue: 62 percent minimum
- The base asphalt cement should meet the requirements of an AC-20

Following are the mix tests recommended by the TTI design procedure.

2.4.5.1 Estimation of Optimum Binder Content

This procedure uses the ASTM D5148-90 test method for Centrifuge Kerosene Equivalent (CKE) to estimate the optimum residual asphalt cement (RAC) content for a given micro-surfacing system.[(52)] The procedure described in ASTM D5148 can be used to determine the Approximate Bitumen Ratio (ABR) which would be used with hot mix asphalt concrete. For micro-surfacing, the optimum RAC to use is ABR plus 2.0 percent. The adjustment is to compensate for 100 percent crushed material and the viscosity of the polymer modified asphalt emulsion. It is recommended to test trial mixtures at the following RAC values: Optimum RAC, +/-2.0 percent, +/- 1.0 percent, and +/- 0.5 percent from optimum.

2.4.5.2 Mixing Test

This test makes use of trial mixtures to identify if the material can be mixed at room temperature for at least 120 seconds and is based on ISSA TB 102 [(53)]. It is recommended that the mixing test be performed at each RAC content with different amounts (0.5, 1.0, 1.5, and 2.0 percent) of portland cement. The water content also is varied from a value necessary to obtain a creamy mixture to lower values by reducing the water content at 1.0 percent intervals in order to obtain the minimum water content. The minimum water content is the one corresponding to a mixing time of 120 seconds. If the mixture cannot be mixed for 120 seconds without breaking, the design is rejected.

2.4.5.3 Modified Cup Flow Test

This test is used to select the optimum water content. The test should be performed at all RAC/cement combinations used in the mixing test. The optimum water content is selected at 2.0 percent below the water content that gives greater than 5 mm (0.2 in) separation of fluids and solids. The optimum water content should be greater than the minimum obtained in the mixing test. If it is less, the design is rejected.

2.4.5.4 Modified Cohesion Test, ISSA TB 139

The test is discussed in Section 2.4.1.2. The test is performed at each RAC/water content combination and the following portland cement contents: 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, and 2.5 percent. For each RAC/water content combination, the designer selects the cement content necessary to obtain a cohesion torque > 12 kg-cm at 30 minutes and > 20 kg-cm at 60 minutes (quick-set system).

2.4.5.5 Wet-Track Abrasion Loss Test, ISSA TB100

The WTAT test is described in Section 2.4.1.5. This test is performed for all RAC/water/cement combinations to determine the lowest RAC content needed to obtain a maximum average WTAT loss of 807 g/m^2 ($75 g/ft^2$) for 6-day soaked samples.

The optimum RAC content is selected by determining the minimum RAC content that passes this test, plush 0.5 percent to account for variability.

2.4.6 Other Design Methods/Guidelines/Specifications

Several other mix design methods are available in the United States and around the world; however, they are not as well known or as widely used as the ISSA or ASTM procedures. These methods are briefly discussed in this section of the report.

2.4.6.1 Proposed Performance Design Method by Benedict, 1985 [54]

Robert C. Benedict was one of the most active researchers and supporters of slurry seal and micro-surfacing paving systems in the United States and the world. As he approached the end of his career, Benedict recognized the need for a performance-based mix design method and, in a paper presented at the 23rd ISSA Annual Convention in 1985, he proposed a new, performance based method for the design of these mixtures. [54]

The proposed method is outlined here:

- Perform a 6-day soak WTAT test (instead of a 1-hour soak) to obtain the system evaluation number (SEN), which is the percent bitumen required to establish a loss of 75 g/ft^2 (80.7 g/m^2). Use this number as a measure of long term wet adhesion.

- Perform an LWT and correlate the results with Marshall stability; obtain a loaded wheel number (LWN), which is the number of cycles to zero compaction or percent compaction at a given number of cycles. Also, obtain a macrotexture number (MTN).

- Use SEN, LWN, and MTN for performance design (where LWN may be related to traffic load).

However, one year later Benedict presented results of cured cohesion laboratory tests on a range of cured slurry mixes.[55] He found that a change in any single mix ingredient, even fractionally, could alter the results of cured cohesion and other slurry tests dramatically. In addition, it was difficult to establish trends or consistent effects of certain parameters in relation to the measured cured cohesion. He also investigated if Marshall type curves could be established from the cured cohesion test and found that the relationship between cured cohesion and percent emulsified asphalt may take various shapes. Very few cases resemble the curves usually found in a Marshall stability test.

2.4.6.2 ISSA TB111 – Outline Guide Design Procedure for Slurry Seal [56]

ISSA Technical Bulletin 111 was developed from papers presented by Huffman, Benedict, Gordillo, and others at the ISSA World Congress in Madrid and the Asphalt Emulsion Manufacturers Association (AEMA) convention in Phoenix, in 1977. The bulletin presents a proposed design procedure for slurry seal. Different from the ISSA Guidelines (A 105), the method suggests ranges of variation for the input design variables and a method to choose the optimum design. The method has two parts:

<u>Part I – Preliminary Design Considerations</u>

1. Describe the pavement to be treated (e.g., surface condition, climate, and traffic information).
2. State the objectives of treatment (e.g., skid resistance, crack filling, rut correction).
3. Evaluate and select materials (e.g., aggregate, emulsion).

<u>Part II – Job Mix Formula Procedures</u>

1. Estimate pure asphalt requirement (PAR) by surface area method.
2. Determine the system compatibility determination.
    - 2.a Estimate optimum water content, filler requirement and mix-set-traffic/cure time characteristics (ISSA TB102).[53]
    - 2. b Cone consistency tests to obtain 2.5 cm consistency (ISSA TB106).[41]
        - 2.b.1. Determine optimum mix-water content for three levels of emulsion content: 100 percent, 85 percent and 70 percent PAR for 2.5 cm consistency.
        - 2.b.2. Adjust filler content, water content and PAR for changes in mix-set-traffic time if required.
        - 2.b.3. Construct 3-point consistency mix-water curve for consistency ranges of 2-3 cm, 4-5 cm and 6-7 cm ranges for each of three PAR levels selected. Air dry at ambient and save each specimen.
    - 2.c Compatibility test.
        - 2.c.1. Examine cross-section of centrally split consistency specimens for evidence of asphalt or aggregate migration.
        - 2.c.2. If suspicious non-uniformity is observed, run Cup Compatibility test.
        - 2.c.3. Wet stripping test.
3. Determine traffic/cure time.
4. Mix tests.
    - 4.a WTAT
    - 4.b LWT
5. Selection of optimum design.
    - 5.a State maximum limits to WTAT=minimum asphalt content.
    - 5.b State maximum limits to LWT= maximum asphalt content.
    - 5.c State job tolerance limits.
    - 5.d Draw graphs of physical test data and superimpose the stated limits and read optimum asphalt content.

2.4.6.3 European Standards EN 12274-1 to 12274-8 Slurry Surfacing Test Methods Part 1 to Part 8 (16-23)

The European Standards (EN) contain descriptions of test methods, which in most cases are very similar to the ISSA Technical Bulletins. These test methods include:

- EN 12274-1: Sampling for binder extraction
- EN 12274-2: Determination of residual binder content
- EN 12274-3: Consistency test (similar to ISSA TB 106)
- EN 12274-4: Determination of cohesion of the mix (similar to ISSA TB 139)
- EN 12274-5: Determination of wearing (similar to ISSA TB 100)
- EN 12274-6: Rate of application
- prEN 12274-7: Shaking abrasion test (similar to ISSA TB 144)
- prEN 12274-8: Visual assessment of defects

A specific standard for the mix design method to be used for slurry seal or micro-surfacing does not seem to be available at this time, however, it is highly likely that the mix design methods used in Europe are based on the ISSA procedures.

2.4.6.4 Technical Guideline: The use of Modified Bitumen Binders in Road Construction (24)

The technical guideline was published in 2001 by the Asphalt Academy, the Council for Scientific and Industrial Research (CSIR), and South Africa. CSIR guidelines are provided for the selection, manufacture, handling, application, and testing of modified binders. For slurry seal and micro-surfacing applications, two types of emulsions are recommended: SC-E1 and SC-E2. The requirements for the two polymer modified emulsions are given in Table 2-5.

TABLE 2-5 Pro Properties of Polymer Modified Emulsions for Surface Seals(24)

Property	Unit	Min/Max	Test Method	Modified Binder Class			
				SC-E1		SC-E2	
Modified Binder Content	(%m/m)	-	MB-22	65-68	70-73	65-68	70-73
Viscosity @ 50°C (Saybolt Furol)	Sec.	-	MB-21	51-200	51-400	51-200	51-400
Residue on sieving	G/100ml	Max	MB-23	0.5		0.5	
Particle Charge	-	-	MB-24	Positive		Positive	
Sedimentation after 60 rotations	-	-	SABS 548	Nil		Nil	
Properties of recovered binder residue			MB-20				
Softening Point	°C	Min	MB-17	48		55	
Ductility @ 15°C	cm	Min	MB-19	75		50	
Elastic recovery @ 15°C	%	Min	MB-4	50		55	
Torsional recovery @ 15°C	%	-	MB-5	Report		Report	
Force ductility	N	-		Report		Report	

In addition, a minimum road temperature for surface sealing is specified: 10°C (50°F). Project selection guidelines have been developed and are given in Table 2-6.

TABLE 2-6 Selection Criteria for Surface Seals[24]

Condition	Modified Binder Class	
	SC-E1	**SC-E2**
Active cracks		X
Passive cracks	X	X
Moderately stressed areas	X	
Highly stressed areas		X
Surface temperature at application > 10°C	X	X
Very high road surface temperatures		X

2.4.6.5 Austroads – Guide the Selection of Pavement Surfacings [25]

The document provides guidelines to asset managers, maintenance engineers and supervisors on the characteristics of road surfacings and to assist in the process of selection of appropriate road surfacings for particular conditions. Slurry seal and micro-surfacing are considered among other options: sprayed seals, asphalt surfacings, and portland cement concrete. According to the guide, slurry seals must be placed on a sound pavement due to the relative brittleness of the material and its poor resistance to reflective cracking. By comparison, micro-surfacing has greater resistance to rutting, greater durability and increased flexibility. The reported benefits of using slurry seal and micro-surfacing treatments are summarized in Table 2-7.[25]

TABLE 2-7 Effect of Slurry Seals and Micro-Surfacing on Existing Surface Characteristics[25]

Property Requiring Improvement	Micro-Surfacing Effect	Slurry Seal Effect
Bitumen aging/oxidation	Delays further oxidation	N/A
Roughness	Some improvement, more with multiple layers	N/A
Water-proofing properties	Minor improvement	N/A
Skid resistance	Fine texture good at low speeds but may reduce at high speeds	N/A
Structural strength	No effect	Minimal to no effect
Robustness (related to sharp turning traffic)	Moderate	N/A
Water spray reduction	Minimal effect	N/A
Permeability of surface	Moderate to high	N/A
Flexibility	Poor	N/A
Shape correction ability	Some improvement, more with multiple layers	N/A
Surface reflection cracking	Poor	N/A
Likely life of treatment	5 to 10 years	N/A

2.5 PERFORMANCE OF SLURRY SEAL AND MICRO-SURFACING SYSTEMS

This section summarizes the main aspects of slurry seal and micro-surfacing performance, based on observations made by various agencies on existing projects. The specific distress modes and the parameters that can be correlated with the observed performance are identified.

2.5.1 Distress Modes

Distress modes that are encountered in slurry seal and micro-surfacing systems can be divided into two categories:

- Those specific to slurry seals and micro-surfacing
- Those addressed by slurry seals and micro-surfacing

The distress modes specific to slurry seals and micro-surfacing can further be divided into short-term and long-term distresses. Short-term distresses may occur during construction or immediately after construction. Long-term distresses are characteristic of the cured, in-service mix.

2.5.1.1 Short-Term Distresses

Short-term distresses are usually the result of inappropriate design, premature opening to traffic, poor workmanship, and pre-existing pavement conditions. Short-term failures can also happen due to sudden changes in temperature and humidity. Both temperature and humidity influence the set and cure time of these mixes. The most common modes of short-term failure include:

- Flushing: This is the result of excess water floating the aggregate fines to the pavement surface. Flushing can also be observed when the asphalt content is too high in which case it is accompanied by loss of skid resistance.

- Raveling: This occurs when the asphalt content is too low.

- Poor surface texture (wash boarding and segregation): This is caused by vertical movement in the spreader box.

- Early traffic damage: This occurs when the pavement is open to traffic before the treatment has cured enough to resist traffic.

- Delamination: This is the result of poor surface preparation (dirty surface).

- Poor appearance: This is the result of poor handwork at edges, overlapped construction joints, drag marks, poor starts, and stops.

- Premature distress: This occurs when the mix is placed on an unsound pavement . The slurry seal or micro-surfacing system will reflect the underlying distress in the pavement that is covered (e.g., cracking, pumping).

2.5.1.2 Long-Term Distresses

The most common mode of *long-term distress* is surface wear (i.e., abrasion and delamination). Wear is a result of loss in fines due to traffic and oxidation of the binder. Wear is expected to occur between five and seven years of service life.

2.5.1.3 Distresses Addressed by Slurry Seals and Micro-Surfacing

In order to differentiate between failure and misuse, failure has to be defined relative to the intended use of slurry seal and micro-surfacing systems. Often times these systems are misused to correct structural problems such as reflective cracking or rutting in pavements in which rutting continues to develop under traffic loads. It is important that agencies understand that the primary purpose of these surface maintenance systems is to extend the pavement life by restoring skid resistance, restoring smoothness, and by sealing the joints and cracks in the existing pavement. Micro-surfacing in particular is used to fill ruts, but only in pavements where rutting is not advancing. Note that these systems do not increase the structural capacity of the pavement and do not prevent cracking from progressing into the surface treatment.

2.5.2 Existing Field Projects

2.5.2.1 Caltrans Micro-Surfacing Pilot Study [26]

The Caltrans study consisted of the evaluation of 9 micro-surfacing projects, constructed during the 1999-2001 time period.[26] All 9 projects were evaluated in terms of surface texture and uniformity, standard of construction joints, uniformity of handwork, cracking, raveling, delamination, and other distress modes. The conclusion resulting from the review was that micro-surfacing was a good surfacing system for preventive maintenance; however, several important issues were identified:

- Workmanship: Many of the problems found on the 9 sites were related to workmanship (poor construction joints, poor starts and stops, poor surface texture in intersections, rough handwork).

- Job Selection: In several cases, the existing poor pavement condition resulted in the early distress; untreated cracks contributed to early delamination and reflective cracking in the micro-surfacing layer.

- Climatic/Traffic Conditions: The climatic and traffic conditions at lay down were found to be important. Where the lay down conditions were cool and damp, cure took longer and in some cases, raveling under traffic was observed.

2.5.2.2 Texas Transportation Institute Micro-Surfacing Study (5,6)

Field trial projects in Brownwood, Bryan, Corpus Christi, Dallas, Houston, Lubbock, San Antonio, Tyler, and Waco Districts were visited and evaluated by TTI personnel. The purpose of these field trial projects was to evaluate the effectiveness of existing mixture designs and quality assurance procedures. Quality assurance checklists were used in evaluating these sites. It was found that micro-surfacing can be used effectively both in preventive and corrective maintenance, primarily for restoring skid resistance, filling ruts to restore transverse surface profile, and to repair weathering or raveling. Other important findings include:

- The most common mixture problems are related to the aggregate having too many fines or containing plastic fines based on a low sand equivalency value.
- Other major problems are generally related to the construction and the skills of the crew. This is similar to the findings from the Caltrans.

2.5.2.3 Ontario Ministry of Transportation Micro-Surfacing Study (27)

In this study, two trial micro-surfacing projects were built in 1991 on Freeways 401 and 403 in the Province of Ontario, Canada. Both sites selected for maintenance treatment exhibited map cracking and raveling. The sites were evaluated immediately after construction and six months after construction. Micro-surfacing was found to provide a viable alternative rehabilitation technique for extending the pavement life on high-speed, high-trafficked freeways suffering from severe surface distress. It was also found that micro-surfacing provided a highly skid-resistant surface and a ride quality within the comfortable range. The ambient weather conditions were found to considerably affect the constructability of micro-surfacing and a skilled crew that can make the slight adjustments required to the mix design on the fly is desirable.

2.5.2.4 Friction Evaluation of Slurry Seal Systems, Kansas (28)

In this study, the friction characteristics of micro-surfacing and slurry seal were investigated in airport applications. Five sites were tested in two airports in Kansas. The micro-surfacing and slurry systems were in the range of one to seven years old. Testing was performed on the same sites in 1989 and in 1993. Both treatments were found to provide levels of surface friction similar to or higher than hot mix asphalt.

2.5.2.5 Pennsylvania Department of Transportation Evaluation of Micro-Surfacing Ralumac (29)

This report documents the performance of 11 project sites constructed between September 1984 and October 1991. Micro-surfacing samples were collected and tested for material consistency and conformance to job specification. Skid resistance results were collected through 5 years of service life after construction on several of the 11 sites. The main conclusion of the study was that the product provided a durable wearing course on all the 11 project sites; and long-term skid resistance and wear performance remain acceptable.

Overall, the micro-surfacing treatments compared well with standard dense-graded hot mix asphalt. However, the projects have not provided strong evidence for long-term performance to resist rutting, except where the original rutting measured less than 0.5 in. The micro-surface did not exhibit any problems with debonding from existing pavements. Several projects exhibited minor delaminations and pot holing of the micro-surface. These problems were caused by delaminations and spalling of the underlying pavement. Proper project selection, design, and construction quality control were considered important for good micro-surfacing performance.

2.5.2.6 FHWA-LTPP SPS-3 Test Sites (30)

As part of the Long Term Pavement Performance (LTPP) study, the performance of several preventive maintenance treatments was investigated in experiments SPS-3 (flexible pavements) and SPS-4 (rigid pavements). One of the surface treatments used was slurry seal. The general conclusions from project reviews dated 1993, 1995, and 1999 are that slurry seal systems perform better when placed on pavements in “good” and “fair” condition. Though the increase in pavement life for pavements in fair condition was found to be higher than in the case of pavements in good condition, the resulting total pavement life for both “good” and “fair” treated pavements was about the same. The expected service life of the treatment when applied to good/fair pavements is five to seven years.

2.5.2.7 Transport Research Laboratory Report 314: Road Trials of Stone Mastic Asphalt and Other Thin Surfacings (31)

This report describes a study on the performance of several thin surface treatments including micro-surfacing. Micro-surfacing was applied on one of the 4 sites monitored in the study and the performance of the treatment was monitored over a 5-year period (1992-1997) in terms of skid resistance and visual assessment of the pavement condition. Micro-surfacing provided skid resistance comparable with hot mix asphalt concrete and other thin surface treatments, such as Small Mixture Asphalt (SMA) and Safepave. The skid resistance varied somewhat, but overall it maintained a constant average during the five years of monitoring. The surface condition on the average was acceptable; however, ratings varied from suspect to moderate (acceptable was in between). According to the ratings, the condition of the pavement maintained an acceptable level of performance for the five years of observation; and failures did not occur.

2.5.2.8 MnROAD 1999 State Micro-Surfacing Project (32)

The purpose of MnROAD, the Minnesota DOT (MnDOT) study, was to introduce and investigate the use of micro-surfacing in the state, as a preventive maintenance treatment as well as a method to correct or prevent defects in existing pavements. The study included 15 State highway and interstate pavement sections ranging from 1 to 10 miles in length. The existing pavement condition varied from one section to another and so did the purpose of using the micro-surfacing. The purpose of using the micro-surfacing included:

- Retard disintegration of road surface for five years until total re-construct
- Correct raveling

- Correct stripping of hot mix asphalt (HMAC)
- Ride restoration
- Rut filling
- Rut filling and surface course
- Preventive maintenance
- Repair damage on road shoulders
- Increase friction to reduce accidents
- Test micro-surfacing at MnRoad test site

The micro-surfacing was designed according to the ISSA method and both the Type II and Type III aggregate gradations were used. Two sources of aggregate (in both cases granite) were used. All construction work was performed by a single contractor using a continuous micro-surfacing machine, according to MnDOT's specification.

The findings of the project are in agreement with the other field projects included in the literature search:

- Micro-surfacing is a fast moving process that allows early return to traffic. The contractor averaged four lane-miles per eight-hour day of construction.

- Micro-surfacing does an excellent job of re-establishing cross-sections. When the cross-section profile is greater than 6 mm (¼ in) it is recommended that a scratch course be used, covered by a surface course. A scratch course is constructed using the normal paving box for applying a surface course, but the primary rubber screed is replaced with a steel bar.

- It proved effective in rut-filling applications. If the ruts are less than 12 mm (½ in) deep and vary in the location in the lane, a scratch course is recommended to fill the ruts. For ruts with a depth greater than 12 mm (½ in), a traditional rut box with a V-shaped screed is recommended.

- Micro-surfacing improves ride quality through leveling cupped transverse cracks, dips, and edge drop offs. However, it does not work favorably for smoothing humps in the pavement. It increases friction numbers and provides an excellent background for pavement markings.

- Micro-surfacing will not stop reflective cracking and will not fix any structural problems the pavement might have. It should not be used to fill ruts in pavements in which rutting is still developing. Potholes should be repaired prior to the application of the treatment. Project selection is therefore a key factor in the overall success of the micro-surfacing project.

- On two of the fifteen sites included in the study, micro-surfacing was used with moderate success to correct raveling and stripping of the HMAC layer. Note, however, that performance data for these sites was available only immediately after construction (1999) and one year after construction (2000).

All of the sections of the Statewide micro-surfacing study were monitored for three years of service. They were all performing satisfactorily at the end of the three years.

2.5.2.9 City of Saskatoon, Saskatchewan, Canada, Micro-Surfacing Program (33)

In 1996, the City of Saskatoon, Canada, adopted a yearly micro-surfacing program. The objectives of the program were to repair road failures, ensure that there is positive drainage from the pavement surface, and to resurface the pavement with micro-surfacing. Based on a life cycle cost analysis, it was found that the five-year funding requirements for micro-surfacing the network would be approximately $5.2 million Canadian ($3.9 million). By comparison, if the traditional methods of treatment were used, the average annual investment required to keep streets in a similar overall condition was estimated at $10.8 million Canadian ($8.1 million). The traditional treatment method normally is used to perform routine maintenance until the road fails and then it is reconstructed.

In 2000, the City administration reviewed the condition of the micro-surfaced streets in order to determine whether the treatment was meeting the desired intent. Failures were measured and categorized as either delamination or surface wear. Of the almost 500,000 square meters (~600,000 square yards) that were rated only 1.1 percent had failed. Further analysis showed that, on average, micro-surfacing on residential streets was failing at a rate of 0.4 percent per year that exceeded the administration's expectations and confirmed observations that the treatment is performing extremely well.

2.6 PERFORMANCE RELATED TESTS

2.6.1 Short-Term Performance/Construction

As discussed at the beginning of this chapter, a multitude of factors can affect the placement and immediate performance of slurry seals and micro-surfacing systems:

- Temperature and humidity at the time of placement when different from the temperature/humidity conditions used in design.

- The accurate estimation of break time, set time, traffic time, and cure time.

- Preparation of existing surface.

The consensus of the findings from the literature and the surveys is that the following tests are most closely related to the early performance of the mix:

- The Mixing Test, ISSA TB 113
- The Modified Cohesion Test, ISSA TB 139

These tests provide an indication of the proper consistency of the mix and provide estimates for the break time, set time, early rolling traffic time, and cure time. All these parameters are crucial for the proper placing of the mix and to avoid premature opening to traffic when the mix is not strong enough to sustain traffic loads. However, it should be noted that both the mixing test and modified cohesion test are usually performed at room temperature and approximately 50 percent humidity. To properly account for the effects of temperature and humidity these tests should also be performed at the expected temperature/humidity field conditions.

2.6.2 Long-Term Performance

Of all the tests involved in the design of slurry seal and micro-surfacing systems, very few are considered to be related to the long-term performance of the mix. According to the literature, the most important of these is the WTAT loss, obtained from the *Wet Track Abrasion Test,* and included in all five design methods presented in this study. Coyne and Kari, in their paper "Emulsified Asphalt Slurry Seal Coats," found that WTAT loss could be correlated with the rate of field wear for slurry seal. (57) In addition, in response to question number four of the industry questionnaire, the great majority of respondents indicated the WTAT test can be related to the long-term performance of the mix.

Another test considered by the survey respondents to be a good indicator of long term performance is aggregate filler, a bitumen compatibility test determined in the *Schulze-Breuer and Ruck Procedures*, ISSA TB 144.(50) The method involves testing and ranking of a mix in terms of abrasion loss, adhesion, and integrity. The test is included and described in more detail as part of the ASTM design method for micro-surfacing.

A third candidate test to be used as an indicator of performance is the *Loaded Wheel Test*. However, according to the TTI reports and the surveys, the results are not always repeatable.

2.7 EXISTING GUIDELINES AND SPECIFICATIONS

The existing guidelines and specifications for slurry seal and micro-surfacing are very similar and they address the various aspects of slurry seal and micro-surfacing design and construction including:

- Materials selection and quality tests
- Laboratory evaluation of the mix
- Rate of application
- Tolerances for individual materials as well as the mix
- Equipment (mixing, proportioning devices, spreading, auxiliary equipment, calibration)
- Weather limitations
- Notification and traffic control
- Surface preparation
- Application
- Quality control
- Payment

In addition, the TTI and Caltrans studies contain guidelines and recommendations for *project selection*. As discussed earlier, the performance of slurry seals and micro-surfacing systems is greatly affected by the pre-existing condition of the pavement on which the treatment is applied. As mentioned in these two studies and, judging from the results of several existing field projects described in this report, slurry seal and micro-surfacing will not prevent cracking from reflecting on the new surface and will not stop rutting on a pavement on which permanent vertical deformation continues to develop. Micro-surfacing can be used for rut-filling where no more vertical deformation is occurring. Both slurry seal and micro-surfacing systems can be used on raveled, aged pavements, to restore skid resistance and smoothness. Both systems also will seal the joints and cracks in the existing pavement and slow the rate of deterioration of the existing pavement.

2.8 SUMMARY OF FINDINGS

As a result of the literature review and the responses to the industry, agency, and advisory panel surveys, several key issues regarding the current state of practice in the design and construction of slurry seal and micro-surfacing systems have been identified and include the following:

- In both the ISSA and ASTM, design methods it is clearly noted that the methods should only be used as a guide and that end-use specifications should be adapted to conform to job and user requirements. It is desirable to develop a more exact method that will provide successful mix designs based more on additional information used as input in the design method rather than relying heavily on the experience of the construction crew with these types of treatments.

- All methods investigated are rather vague in describing the minimum number of replicate tests, the number of test specimens, and the range of conditions to be used with a specific test (e.g., range of variation in temperature, humidity, soaking time). It would be helpful to provide these details for every laboratory test used as part of the design procedure.

- The test specimen geometry and method of preparation are different from one test to another. Ideally, to reduce variability due to specimen geometry, size, and method of preparation, all tests should attempt to use similar test specimens so that several tests could be performed on the same test specimen.

- In all tests, the aggregate particles larger than No. 4 US Sieve are scalped off. Ideally, a larger test specimen should be used in order to maintain the original gradation of the mix in the test specimen.

- The repeatability of all recommended laboratory tests should be investigated.

- The guidelines and specifications for the design of slurry seal and micro-surfacing systems are very similar and do not need to be treated separately. A single method that could be used to design both slurry seal and micro-surfacing would contribute to the simplification and clarification of the design and construction guidelines for these treatments.

- The great majority of the existing slurry seal and micro-surfacing field projects contain information on the short-term performance of these systems, but very few studies contain any long-term performance data. As information from other studies not included at this time in the literature review become available, this report will be updated to reflect the increased availability of long-term performance data.

- Clients and agencies should be educated on the purposes, mechanisms, and options available in the framework of the preventive maintenance concept. This will help them differentiate between failure and misuse of these treatments and provide them with a better understanding of the project selection process.

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CHAPTER 3 PROPOSED WORK PLAN FOR PHASE II

This chapter presents the work plan to develop an improved mix design procedure based on performance and constructability parameters. The framework for the mix design procedure is first presented, followed by a discussion of the proposed tests to be evaluated and discussion of the plan for evaluating the ruggedness of the tests.

Please note that this Chapter does not exactly follow the Phase II outline contained in the original proposal. This is because, upon commencement of the actual work, the project team considered the proposal outline to be in need of modification. As a result of the literature review and the surveys, the project team concurred that it was necessary to cover the essential elements in a logical fashion. For example, the proposal work plan identified a separate item for evaluating constructability parameters. However, instead of treating all matters related to construction in one place, the different aspects of construction are discussed in various sections of the report as they relate to that section.

3.1 FRAMEWORK FOR A NEW MIX DESIGN PROCEDURE

3.1.1 Philosophy

Below is the problem statement and objectives taken from the original proposal:

> "The current ISSA procedures for Slurry Seal Mix Design (A105) and Micro-surfacing (A143); and Practices for Design, Testing and Construction of Slurry Seal (ASTM D3910-98) and Practice for Design, Testing and Construction of Micro-Surfacing (ASTM D6372-99) all have their origins in the 1980's before the wide-spread use of micro-surfacing and the use of polymer modified emulsions in slurry seals. To date, these test methods and design procedures have been used because no newer test methods or mix design methods have been developed. Recent Texas Transportation Institute studies documented the problems associated with using the existing methods for micro-surfacing and suggest that comprehensive mix design and analysis procedures need to be developed. While differences exist between slurry seal and micro-surfacing applications (i.e., traffic volume, application thickness and curing mechanisms), the similarities of the tests used currently indicate that the two systems should be studied together. New mix design procedures for slurry seal and micro surfacing that address performance needs of the owners and users, design and application needs of the suppliers, improve the reproducibility of the designs are needed. If successful, this project will improve the credibility and consistency of the products and elevate these surface treatment methods to the highest levels of acceptance."

The new and improved mix design procedure(s) should establish the level of components in the mixture and the tests run should relate to field performance. The mix design procedure(s) should also address several specific aspects:

- Mixing characteristics: This will ensure that the emulsified asphalt, aggregate, mineral filler, water and control additives can be mixed, coated and applied through the machine in a continuous fashion.

- Setting and curing characteristics. This will establish that the applied mixture sets to a rain-safe condition quickly and cures within a reasonably definable time to allow return of traffic without segregation, raveling, displacement, or flushing.

- Long-term performance. This will provide for a mixture that maintains good friction resistance, does not ravel, debond, bleed, exhibit moisture damage, or lose cohesiveness over the life of the treatment.

The mix design procedure(s) will establish the emulsified asphalt residue ranges and total liquids as well as the control additives necessary to achieve the performance parameters above. Mineral filler content will be determined to achieve proper flow characteristics as well as setting and curing properties. Selecting the proper gradation for the aggregates should address performance, traffic, and thickness requirements.

3.1.2 Slurry Versus Micro-Surfacing Mix Design

With regard to the mix design of these systems, the team considers that the procedures will be the same for both systems. The difference between slurry and micro-surfacing can be defined in terms of both chemical and performance differences. For the purposes of mix design, however, these chemical differences are not relevant. The mix design methods should simply show the benefit of one system over the other. In terms of field performance, constructability issues (e.g., mixing, placing, finishing) are the same for both slurry and micro-surfacing. The degree to which each system meets the performance requirements for traffic and environment (or fails to meet them) is the main mix design issue. The mix design must attempt to quantify performance requirements and allow the selection of slurry or micro-surfacing systems to meet these requirements. This will not only allow for the development of appropriate specifications for a specific application to achieve the desired performance, but also should promote innovation with material suppliers to improve or extend material performance.

3.1.3 Test Methods and Mix Properties

All of the test methods considered will be evaluated based on the following criteria:

- Ease of use
- Ability to relate to a known performance parameter
- Cost (as far as possible simple equipment and or adaptations of existing methods)
- Repeatability
- Ease of implementation by users

The results of the literature review indicated that the test selection process can be conveniently broken down into several stages that may be expressed in terms of the following questions:

- What materials should be selected? This includes questions of availability and expected performance.
- Will the materials mix? This addresses the issues of constructability (i.e., compatibility, coating, and adhesion). These are basic materials properties.
- Will the mixture spread? This covers the issues of rheology, consistency and break of the mixture.
- Will the mixture set? This addresses the issues of time to cure to achieve a strength that will allow traffic to use the surface without damage.
- Will the mixture last? This covers the long-term performance properties.

This approach allows the design process to be broken into materials properties as well as short- and long-term performance issues that encompass both field performance and constructability. Short-term performance is considered to be from the beginning of construction to one year, while long-term performance is considered to be from one to ten years or replacement. It is currently envisioned that the new design process will incorporate existing equipment (to the extent possible) but, as will be discussed later, some modifications to this equipment may be necessary. New equipment used in other countries also may be included in the design process. The influence of the environment, traffic, and ambient conditions on the mix ingredients will be included in the design analysis process to ensure performance in the field.

3.1.4 Material Properties

Mixing is a function of the individual material properties and their compatibility with one another. However, material properties will also affect performance characteristics during construction and in both short-and long-term performance. Thus, the selection of materials must be the first step to optimize properties and allow for optimization in the selection of additives and additive levels. This includes fillers, fluid levels, and allowance for job conditions (environment) and traffic (volume and loading). The study will seek to set material parameters, which meet existing or newly established criteria. The potential tests under consideration are noted in Table 3-1.

The water used in the design and construction process should be potable and the mineral fillers should meet the requirements of AASHTO M 17-99 (ASTM D242-00) for mineral filler and AASHTO M85-03 (ASTM C150-02) for portland cement.[1-4]

TABLE 3-1 Potential Materials Tests

Component Materials	Current/New Methods	Defined Property
A. BINDERS		
Emulsion & Binder		To collect data from conventional design test methods and new SHRP methods in order to measure properties of thermal susceptibility
Residue Recovery: Distillation Evaporation Forced Fan Evaporation	AASHTO T59 ASTM D244 CAL 331	Emulsion binder/solids content; Determining the best method of residue recovery which does not destroy polymer characteristics
Penetration	AASHTO T49 ASTM D5	Standard & low temperature parameters; Performed at 15°C, 25°C
Ring & Ball Softening Point	AASHTO T53 ASTM D36	Index of residue flow at temperature
Dynamic Shear Rheometer	AASHTO TP5	Stiffness parameters G*/sin d
Bending Beam Rheometer	AASHTO TP1	Low Temperature stiffness
Direct Tension Test	AASHTO TP3	Low Temperature stiffness
Sliding Plate Viscosity		Standard & low temperature parameters; Measuring thin film viscosity characteristics on aged and un-aged binders/residues
Pressure Aging Vessel	AASHTO PP1	Aging characteristics of binder/residue
B. POLYMERS		
Polymers	Types allowed	Identify for specific characteristics of polymers that would better ensure desired residue properties
C. AGGREGATES		
Aggregates: Sieve Analysis	AASHTO T27 ASTM C136 CAL 202	Add requirements on fines grading less than 75um; Further evaluate aggregate size proportions
LA Abrasion	AASHTO T96 ASTM C131 CAL 211	Aggregate hardness quality
Sulfate Soundness	AASHTO T104 ASTM C88 CAL 214	Aggregate freeze-thaw resistance
Sand Equivalent	AASHTO T176 ASTM D2419 CAL 217	Aggregate fine particle quality
Durability	AASHTO T210 ASTM D3744 CAL 229	Hardness quality of aggregates in a wet condition

3.1.5 Aggregates

The aggregate test methods used for slurry and micro-surfacing are well established and appear to be functional, at least for the purposes of this study. Therefore, these will not be changed and will be used in their current form initially. If, in the process of the project, it is determined that changes are required, they will be made.

An aggregate successfully used with each of the emulsions chosen will be selected because of proven performance. The purpose of this step is to measure properties of the various aggregates and confirm the ranges in the existing standards. One exception will be the use of the methylene blue test (ISSA TB 145) that is an indicator of both clay content and reactivity. The methylene blue value standardized against the <75μ fraction of the aggregate has been shown by some to be a good indicator of aggregate acceptability.(5) The effect of filler types and percentage addition could be monitored in this way. Aggregates will be chosen from sources with a known performance record with the selected binders.

3.1.6 Binder

The new mix design procedure must be sensitive to binder properties and should allow these limits to be refined for specification purposes (field performance will be based on mix performance). For this reason, the tests to be chosen from Table 3-1 initially will be limited to:

- AASHTO T 59 Residue recovery (perhaps Caltrans 331).(7)
- AASHTO T 49, Penetration.
- AASHTO T 53, Ring and Ball Softening Point.
- AASHTO TP 5, Dynamic Shear Rheometer (G*/sin delta) as per Caltrans existing micro-surfacing draft specification. (6)

Emulsion suppliers will be asked to provide a micro-surfacing and slurry emulsion successfully used in various areas of the United States. This will be discussed further later in this Chapter.

3.1.7 Short-Term Mix Properties

The short-term properties of the mixtures are based on the application (constructability) and the response to load in early life, 0-1 year. Put simply, this means how the materials mix, spread, and cure to an initial state so that it may be trafficked and that the surface survives under the given project conditions up to one year. This is a question of mixing, coating, and cohesion changes with time during mixing, spreading and immediately after placement. Table 3-2 summarizes the various tests considered for evaluation for short-term performance.

TABLE 3-2 Short-Term Performance Tests from Original Proposal

Combined Materials	Current/New Methods	Defined Property
Mixing Time	ISSA TB 113	Available fluid mixing time of all components; Varying temperatures: 10°C, 25°C, 50°C
Mixability Tests	European Cohesion Test	Initial slope of torque curve v. time; Instrumented mixing test with defined mixability index
Workability Tests	European Cohesion Test New: Torque Viscosity	Slope of torque curve v. time after initial mixing; Relates to construction parameters; Increase flow resistance; Varying temperatures: 10°C, 25°C, 50°C
Consistency	ISSA TB 106	Ability of fluid material to flow properly in an un-augered application box; Consistency of mixture in the spreader box stage; Motorized cohesion test or simple cup flow test; Varying temperatures: 10°C, 25°C, 50°C
Spreadability Test	New: Torque Viscosity	Slope of torque curve v. time defined as exiting from mixing box (shear modulus)
Curing Time	ISSA TB 139	Identification of curing time for earliest traffic ability; Varying temperatures: 10°C, 25°C, 50°C
	HILT Bend Test French Test	Identify internal cohesion at traffic time; Varying temperatures: 10°C, 25°C, 50°C
	European Cohesion Test	Identify the build up in cohesion over time; Varying temperatures: 10°C, 25°C, 50°C
Trafficability Test	Oven-cured specimens	Relate cure time test by comparison of oven-cured specimens
	New	Compactability test to determine how long it will take for mix to reach final in-place voids
	New	Permeability of specimens for determining compactability
Additive Effectiveness	Above test methods	Determining the effects of different additives and varying quantities; Varying temperatures: 10°C, 25°C, 50°C

Based on the evaluation criteria, ISSA TB 113 is proposed for use as a basis to determine the mix properties and will be compared against the German mixing test as shown in Figure 3-1. The mixing time for mixes with which the project team has experience, and which perform well, will be determined using TB 113. The mix will then be tested in the German mixing test, and the resultant mixing time will be noted. This will then become the tentative standard. The test will determine a mixability parameter (cohesion limit where coating occurs to >95 percent) and a workability parameter (a cohesion value where the mix will still flow). These will be defined by observing the consistency and be quantified by the cohesion value and shape of the mixing curve. An example of this curve is contained in Figure 3-2. These parameters may be measured over a range of shear values, temperatures, and other parameters.

The mixing test uses a torque transducer to measure stiffness of a mix and it is similar to TB 106. However, the test method is computerized and standardized and has been under development in Germany for a decade.[8] This method (Proposed Test Method [PTM] 001), is described in detail in Appendix D.

FIGURE 3-1a German mixing test [8]

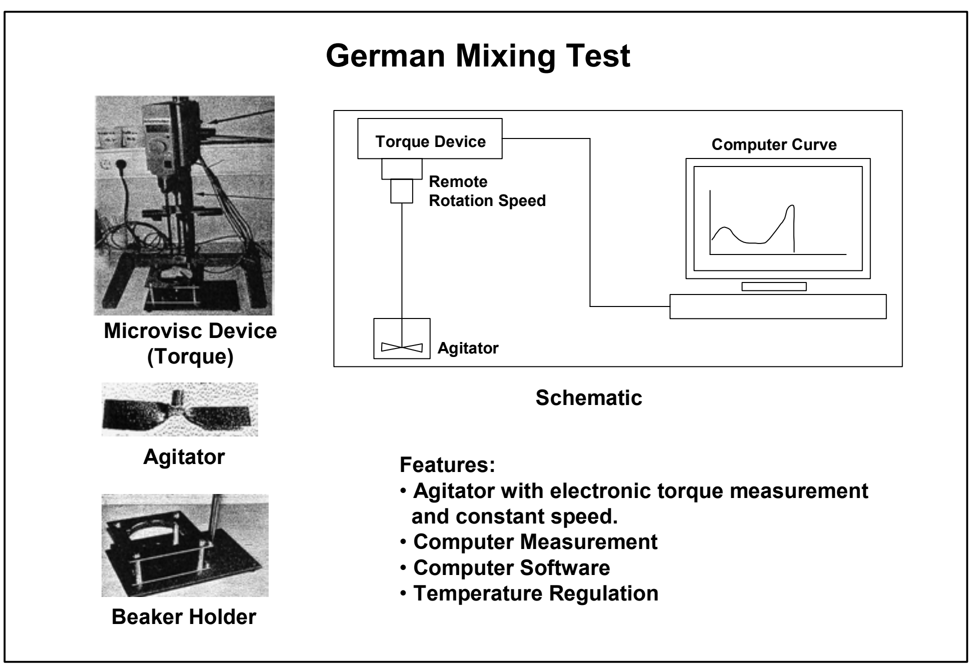

FIGURE 3-1b German mixing test schematic [8]

The intention of this procedure is to use a test that does not require an expert. The test may be carried out at various conditions of temperature and humidity using a controlled climate cabinet or controlled climate room. Outputs from the test are given in Figure 3-2. The mix index is the cohesion when full coating occurs and the mix flows easily; the spread index is the maximum cohesion when mixing is no longer possible, but the mix will spread.

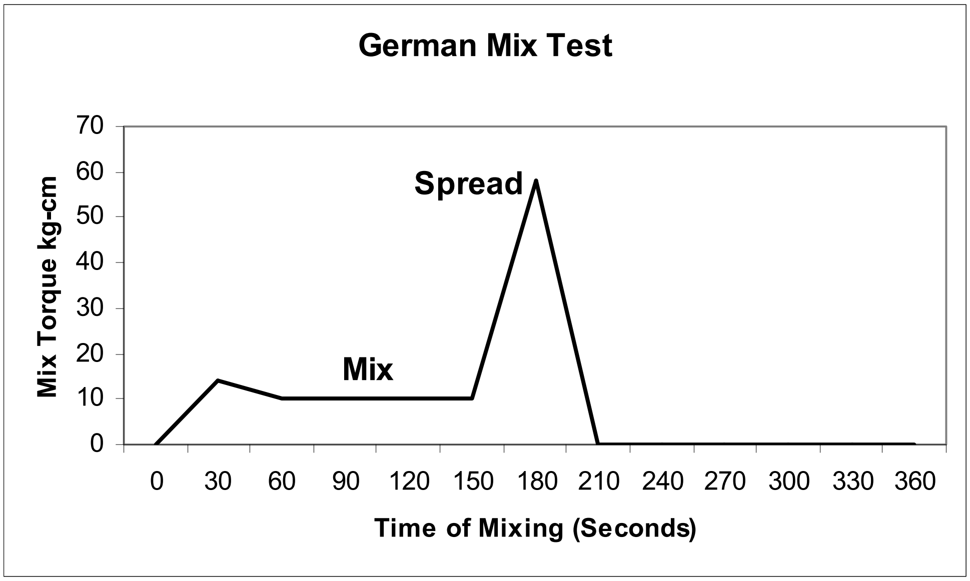

FIGURE 3-2 German mix test cohesion parameters versus time[8]

The test data would be evaluated by observing the indices of the mixes noted above as compared to results from TB 113. In addition, the coating of the aggregate would be evaluated visually as is currently done. This test would determine the preliminary range of mix proportions.

The next step in the process would be to determine traffic time for these mixes. This is a constructability parameter, or a measure of the cohesion the mix must reach in order to accept traffic. This level should be the same for any traffic type, but it may require different times at other application conditions (e.g., temperature, time of day, anticipated rainfall).

The cohesion measurement is thus very important to ensure the mix will perform under traffic. This property will be based on TB 139 to determine the mix and set traffic cohesion as well as a 24-hour cohesion. This may be measured under a range of conditions of humidity, temperature, and darkness to determine the suitability of mixtures for specific application conditions. In addition, the test will be carried out with and without compaction to simulate early traffic or rolling. This method (PTM 002) is described in detail in Appendix E.

Figure 3-3a indicates the intended output from the test. The test will determine the minimum requirement for cohesion based on TB 139 and acceptable mixtures at standard conditions. It also will determine the cohesion requirements at a nominal traffic time of 60 minutes. The 24-hour cohesion will be based on project specific cure conditions. A fully cured value may also be established using oven-cured samples. The test results are expected to provide three specification points for cohesion: mixing, spreading, and traffic. Figure 3-3b provides a schematic drawing of the equipment.

The Hilt test was also considered for measuring cohesion, but was rejected for the mix design due to reported repeatability issues.[9]

The last issue on fresh mixes is that of abrasion loss. Short-term stone retention may also be measured in abrasion. For example, the French WTAT, shown in Figure 3-4, with wheels will be examined and compared with existing TB 100 for reproducibility and actual cohesion/cure values.[10] This test may be performed under different cure conditions as well as used to determine the effect of early water intrusion due to rain. The test method (PTM 003) is described in detail in Appendix F.

Results from this test can be used to establish a limit for stone retention with respect to cure time and conditions. The effect of compaction and early trafficking may also be determined by hand rolling the samples prior to testing and comparing the results to samples that are un-compacted. The steps include the following:

Samples should be cured under the following three laboratory conditions:

- Laboratory “standard” conditions (25°C, 50 percent relative humidity).
- Oven at 60°C.
- Humidity and temperature bath (10°C, 90 percent relative humidity; 40°C, 90 percent relative humidity).

Figure 3-5 shows a simple conditioning system for humidity /nighttime curing of samples that has been used recently for work in Russia.[11] The space at the bottom may contain water with ice for low temperature-high humidity, or hot water for higher humidity. A cooler or heater and a thermostat control the water temperature.

The LWT, may be used to determine the upper limit of bitumen content by determining the amount of sand adhesion in accordance with TB 109. This method needs to be assessed and modified to improve reproducibility. The upper bitumen limit is important to prevent bleeding of mixes in service and this test should be modified to include different conditions. The test will be used as is, but conditioning of samples will be carried out at 15°, 25°, and 35°C to allow for the effects of high shear or high temperature. Deformation in early life is evaluated using cohesion testing.

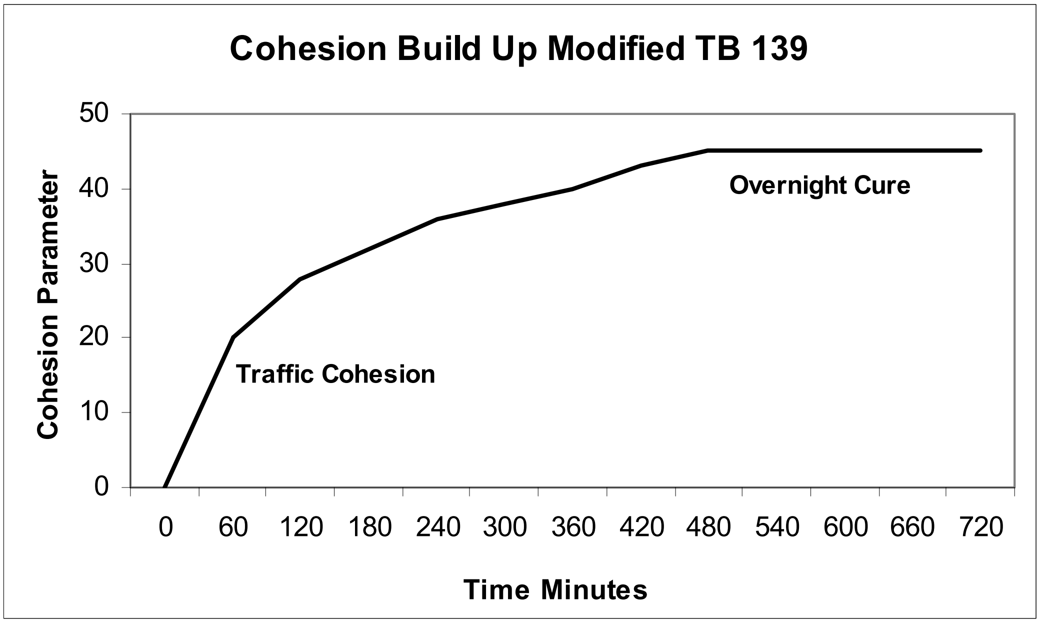

FIGURE 3-3a Modified TB 139 cohesion parameters versus time

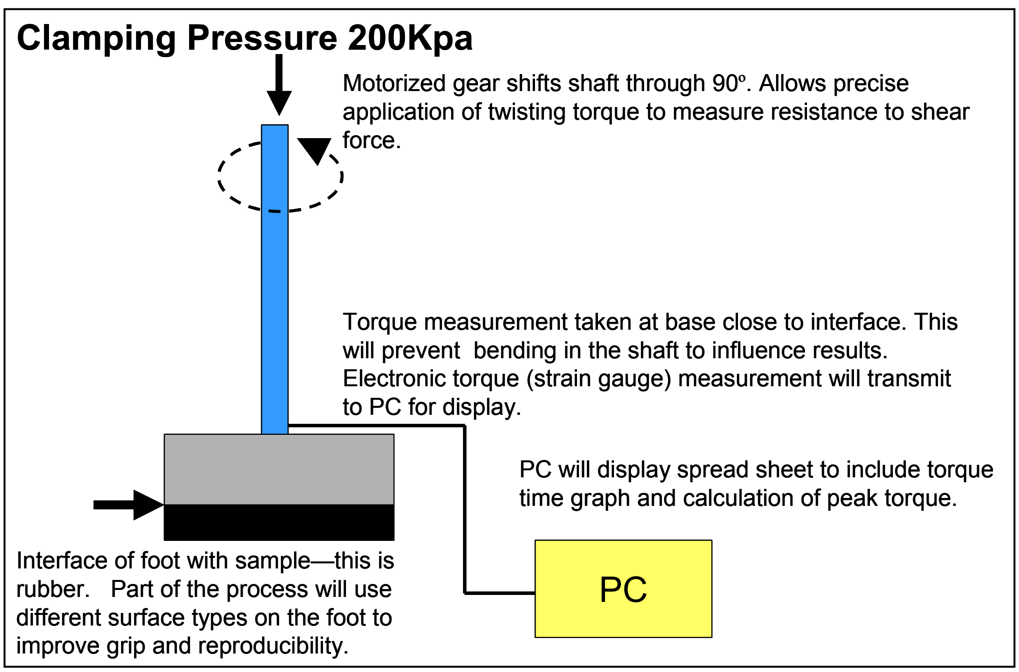

FIGURE 3-3b Schematic of the cohesion test method

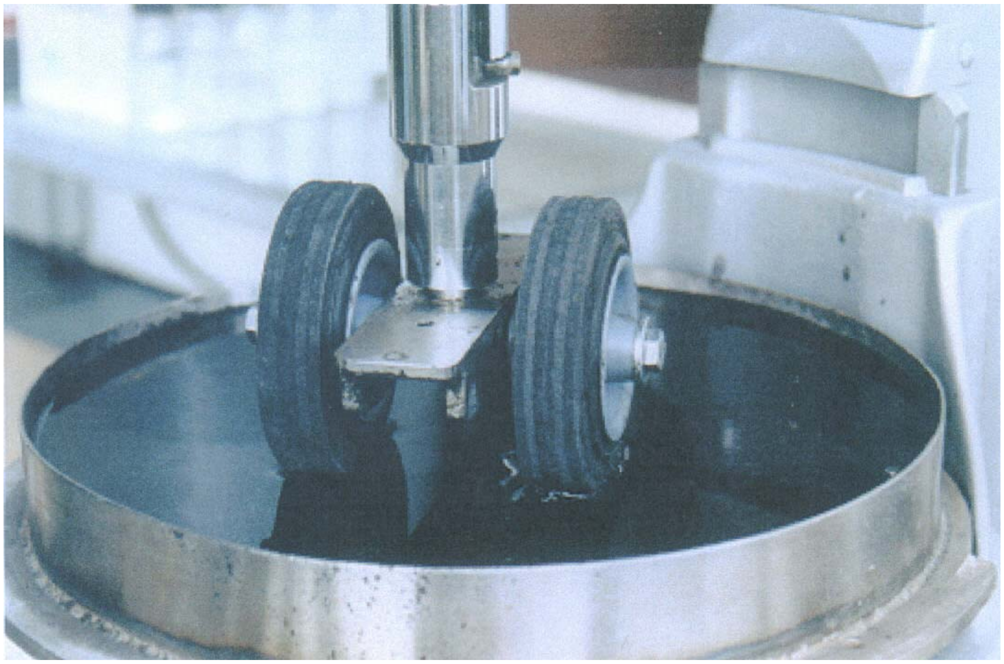

FIGURE 3-4 French Wet Track Abrasion Test[10]

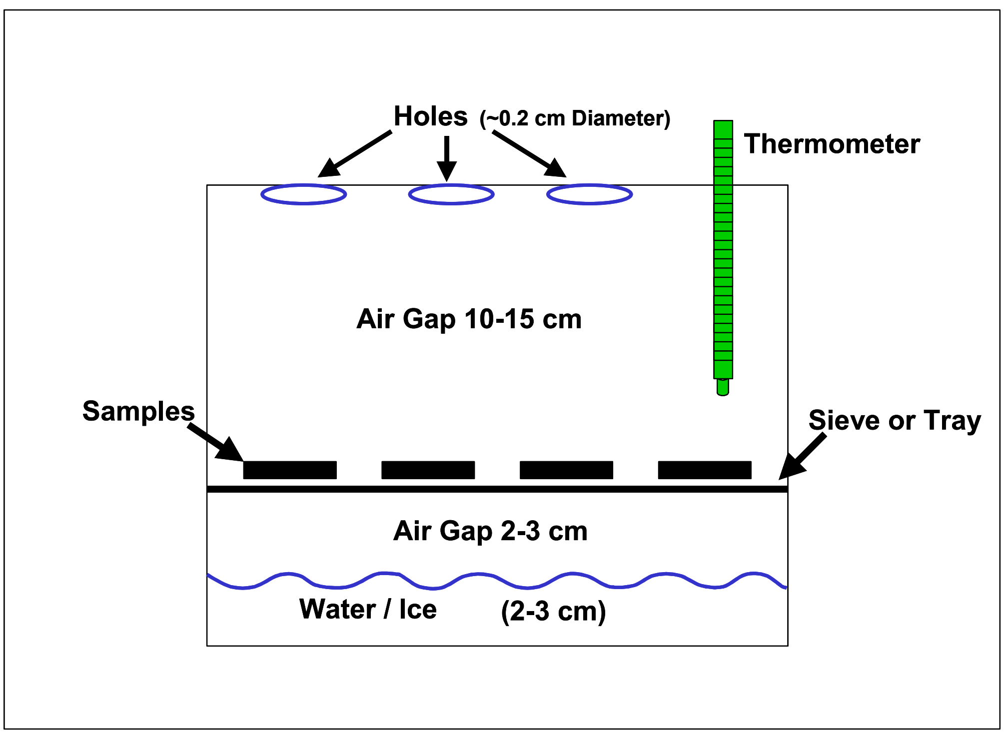

FIGURE 3-5 Proposed curing/conditioning system[11]

3.1.8 Long Term Mix Properties

The long-term properties of slurry and micro-surfacing are dependent on the mechanical properties of the mixes and their ability to maintain these properties over time and under service conditions. This makes them no different from any other thin aggregate/binder mixtures such as thin and ultra-thin hot mix overlays. For micro-surfacing, when the material is placed in thicker layers (up to 100 mm), rut performance becomes important and must be evaluated in the design process. As is noted below, the project team intends to evaluate this property using the Asphalt Pavement Analyzer. Purchase of this equipment is not planned as part of the project, but one or more of the pooled fund States that have this equipment will be requested to perform the necessary testing where they consider rutting to be a problem. Table 3-3 provides a list of candidate tests that were identified in the original proposal.

The main properties of interest for long-term performance include:

- Abrasion resistance - raveling
- Water resistance (stripping)
- Deformation resistance
- Crack resistance

The candidate test methods considered for this study are summarized in Table 3-4. The ones that are recommended for inclusion in this study (ones the project team considers meet the criteria in Section 3.1.3 are as follows:

- Abrasion: TB 100 modified French WTAT. This test may be conducted on fully (oven cured) samples under water and with various conditioning methods including soaking at different temperatures and times, compaction, and different curing cycles.

- Water Resistance: The French Wheel WTAT will be carried out for extended times on fully cured samples under elevated temperature under water. This will be expressed as a ratio of 1-hour soak to 6-day soak and a limit set for acceptable mixes of retained abrasion resistance.

- Deformation Resistance: The Asphalt Pavement Analyzer is only relevant to micro-surfacing that will be used in rut filling applications.

- Crack Resistance: Although these systems are not usually recommended for crack treatments, resistance to cracking should be evaluated during the material selection process. This may involve a surrogate binder test using output from material tests (AASHTO TP5, AASHTO 553).

TABLE 3-3 Candidate Test Methods from the Original Proposal

Combined Materials	Current/New Methods	Defined Property
Initial Target Residual Asphalt Content		Film thickness determinations based on surface area and sieve analysis
Coatability	ASTM D244	Coating characteristics
Wet Stripping	ISSA TB 114 ASTM D3625	Boiling water adhesion
Durability/ Aging/ Stripping	ISSA TB 114 ASTM D3625	Testing compacted mix samples after PAV curing; Stripping test by boiling of aged and un-aged specimens
Stripping Resistance	AASHTO T283	Moisture sensitivity of compacted specimens
Wet Track Abrasion	ISSA TB 100 Modified with French Wheel Method	Minimum asphalt requirements under wet abrasive conditions; One hour soak; Varying soaking conditions of time and temperature
Abrasion Test for cured specimens	ISSA TB 100 Modified with French Wheel Method	Effect of wear on pavement surface over the life. Aging indication on PAV-based or oven-based specimens
Water Sensitivity under wheel load	Modified Hamburg Test	Deformation resistance and water resistance utilizing various testing conditions on the Hamburg test equipment
Water Sensitivity Test	ISSA TB 100	Minimum asphalt requirement under wet abrasion conditions; Six day soak; Varying soaking conditions of time and temperature
Volumetric Criteria	Voids determination before and after compaction New method	Optimize asphalt content based on volumetrics; Determine voids-in-place requirements which would give a mechanical set of properties at allowable residual binder levels
Permeability	NCAT procedure	Determine voids permeability at varying asphalt contents
Excess Asphalt	ISSA TB 109	Maximum asphalt content requirement by measurement of hot sand
Crack Resistance Fatigue Testing	Bruge Bending Test-Modified Reflection Cracking JIG Fatigue Thin Slice	Cracking resistance using fatigue testing or flexural testing
Fuel Resistance	ASTM D	Fuel resistance determinations; Varying residual asphalt contents
Pick up	Modified Hamburg Test	Determining optimum asphalt content which would give acceptable pick up per Hamburg test at varying laboratory environmental conditions
Modulus Loss	Indirect Tensile Test	Modulus test on briquette using an Indirect Tensile test
Lateral Displacement	ISSA TB 147	Measurement of lateral deformation under Loaded Wheel Tester
Deformation Resistance	ISSA TB 147 Hamburg/Creep/Modulus	Deformation of multi-layered system

TABLE 3-4 Candidate Test Methods for This Study

Combined Materials	Current/New Methods	Defined Property
Wet Track Abrasion	ISSA TB 100 Modified with French Wheel Method	Minimum asphalt requirements under wet abrasive conditions; One hour soak; Varying soaking conditions of time and temperature.
Water Sensitivity Test	ISSA TB 100	Minimum asphalt requirement under wet abrasion conditions; Six day soak; Varying soaking conditions of time and temperature.
Deformation Resistance (Rut Filling Applications Only)	Asphalt Pavement Analyzer	Measures the susceptibility to plastic deformation.
Cracking Resistance	Binder Test: AASHTO TP5, AASHTO T53	Measures the ability of the binder to resist cracking.

3.1.9 Recommended Mix Design Method-Version 1

The proposed mix design procedure intended for Phase II work is shown in Figure 3-6. It is listed as Version 1 because the design procedure could change slightly through the course of the project. The new mix design procedure addresses the shortcomings of the existing procedures by examining mix properties that relate to field performance issues. The steps in the proposed mix design procedure are described below.

3.1.9.1 Step 1: Materials Selection

This first step is to choose the aggregate grading based on the existing ISSA specifications. This step involves selecting aggregates that meet the minimum requirements for mechanical and chemical properties in the specifications that will be prepared as a result of this study. To begin, the current ISSA recommendations will be used. Step 1 is subdivided into the following steps, in the order given:

- Selection of the emulsion and binder: This will be largely a matter of supply and desired application conditions, and these parameters will be included in the specifications that will be developed.

- Selection of a locally available potable water source.

- Selection of a mineral filler, portland cement or hydrated lime, which meets the study's specification requirements.

- NOTE: It may be necessary to include a set control additive at the addition rate recommended by the emulsion supplier.

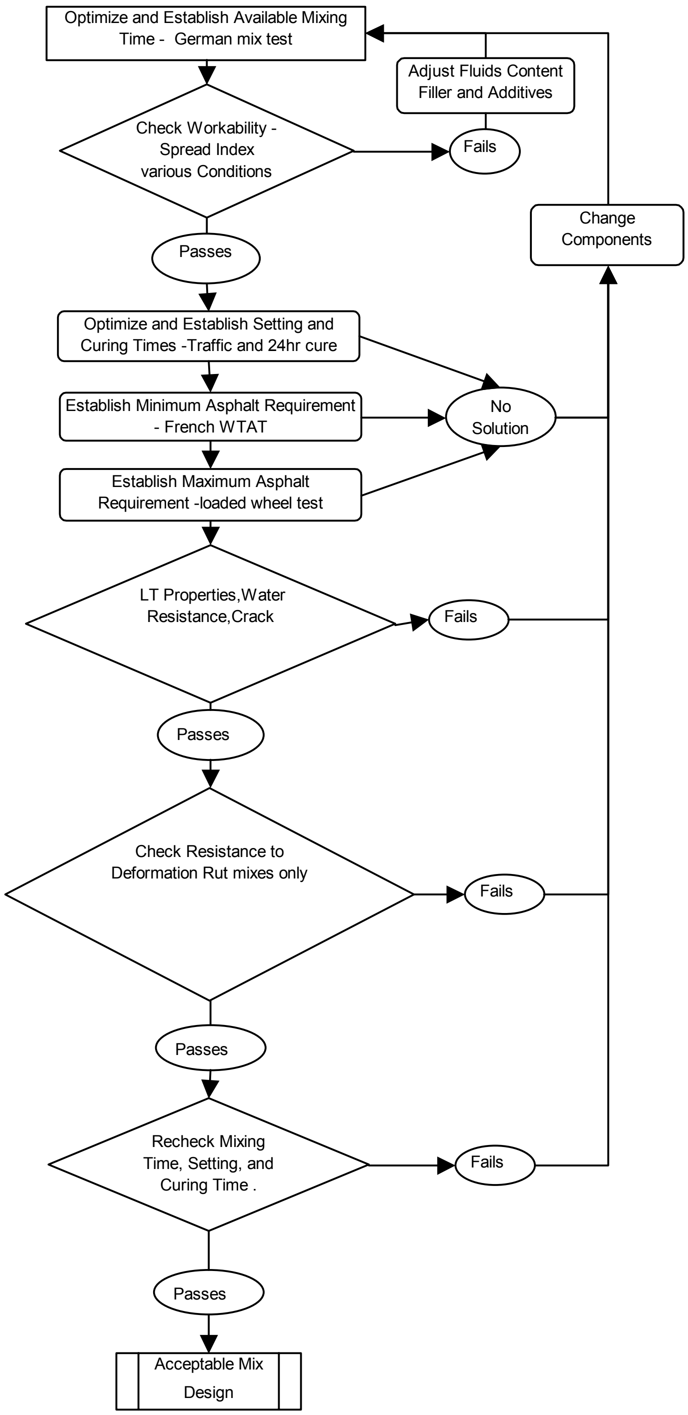

FIGURE 3-6 Proposed mix design flowchart

3.1.9.2 Step 2: Create a Mix Matrix and Determine Mix Constructability

After the materials have been selected, it will be necessary to determine the proportions of aggregate, water, emulsion, and additives and create a mix matrix. This will involve the use of the German mix test to determine the mix and spread indices. These numbers represent the conditions at which the materials can be mixed safely and placed in a timely fashion. These tests will be performed at standard laboratory conditions and repeated for selected mixes for a range of anticipated application conditions.

This process should be repeated with different filler types (if necessary) to optimize the mixture for constructability and performance criteria. This will lead to a recommended filler type and additives levels to be used.

3.1.9.3 Step 3: Determine the Short-term Constructability Properties

This step consists of taking the acceptable mixes and conducting cohesion testing to determine the cohesion at 60 minutes and after a 24-hour cure. This testing would be repeated for specified application conditions of the project. If the results do not meet the standards, then the mixes and materials would be modified as required. In all cases, it is important to ensure that the mix time and spreadability are acceptable. Spreadability is a measure of the ability of the mix to be placed and finished on the pavement surface.

After the proportions have been selected, the modified WTAT should be performed and repeated for anticipated curing conditions to evaluate short-term abrasion properties. At this time, the maximum limits for abrasion loss have not been determined, but the team plans to use the limits that will result from the study.

The mix proportions can then be modified if necessary and a check performed to confirm that the cohesion at 60 minutes provides an acceptable traffic time and the cohesion at the 24-hour cure period is also acceptable.

3.1.9.4 Step 4: Determine the Optimum Binder Content

This involves preparing selected samples for the specific application conditions and varying the emulsion content ± 1 percent from optimum. These samples are fully cured so the additive and filler will be fixed from the above steps.

Under this step the French WTAT will be performed at 1-hour and 6-day soak periods followed by tests using the LWT to determine the excess asphalt at the temperature that corresponds to the proposed traffic conditions (i.e., heavy at 35°C, moderate at 25°C, and low at 15°C).

Finally, the optimum binder content will be selected by evaluating the abrasion loss in the French WTAT and the binder content versus pick up from the loaded wheel tester.

NOTE: The specification minimums established by this study will be used for abrasion loss and the maximum for sand pick up from the LWT.

Step 4 determines the project-specific mix design to be placed in the field.

3.1.9.5 Step 5: Evaluate the Long Term Properties of the Mixture

This step would consist of measuring the following:

- Abrasion: Using the French WTAT.
- Water Resistance: Using the French WTAT.
- Deformation (rut-filling mixes only): Using the Asphalt Pavement Analyzer.
- Crack Resistance: Evaluated using the binder tests.

Finally, any necessary adjustments and recheck of the mixing indices (spreadability, traffic, and 24 hour cohesion) will be made.

3.1.10 Recommended Field Tests

The proposed field tests are based on the delivery of the mix design to the field. The characteristics that are considered important include:

- Surface texture in the final surface. The sand patch test ASTM E965 or similar procedure will be used for surface texture.(12)

- A modified field cohesion test will be used for traffic time.

- The project will also be evaluated using a visual rating system for defects related to:

    - Longitudinal and transverse joints
    - Uniformity and segregation
    - Profile
    - Raveling
    - Bleeding

The basic assessment methods used by the FHWA LTPP Distress Identification Manual will be used to give an overall visual rating.(6

3.2 DRAFT PHASE II WORK PLAN

Based on the results of the literature review, the surveys of users and suppliers, and the experience of the project team, the project team has developed the Phase II Work Plan following the tasks laid out in the original proposal with some slight modifications as noted earlier:

- Task 1: Evaluation of potential (promising) test methods, which includes a constructability evaluation.

- Task 2: Conduct ruggedness testing.

- Task 3: Prepare Phase II report.

This section presents the detailed work plan for Phase II of this study

3.2.1 Purpose of Phase II Study

The literature review and ancillary work has created a basic framework for a new mix design procedure. This must now be validated and the new test methods evaluated so a rugged and useful mix design procedure that addresses the real performance requirements is a deliverable from this effort.

The Phase II work plan will also be used to develop field tests to assist field personnel and agencies to ensure delivery of the mix design and rational mix changes if needed.

The Phase III field studies (discussed later in Chapter 4 of this report) will validate the laboratory mix design procedure, produce proven test methods, and provide field assessment for the pilot projects to be constructed as a part of Phase III.

3.2.2 Task 1 Evaluation of Promising Test Methods

Task 1 is to evaluate the following promising test methods:

- Raw Materials (i.e., aggregate and binder)
- Short Term Performance
- Long Term Performance

3.2.2.1 Aggregate Tests

Two aggregates will be selected from sources where the project team and advisory group have a wealth of experience, as well as from various areas of the United States. The testing plan, to be discussed below, is dictated by the project budget. Tentatively, these are:

- Table Mountain, Basic Materials, Sonora, California, ISSA Type III
- Lopke Gravel Products, Apalachin, New York, Type III.

Test data gathered at the source will be used, verified where possible from agency records and check-tested by the project laboratory.

3.2.2.2 Binder Tests

Two emulsions will be selected, again, from sources with which the project team and advisory group has a wealth of experience. Tentatively these are:

- Koch Ralumac, Waco, TX or Salina, Kansas.
- Polymer Modified CQS-1h, VSS Emultech, Inc., Sacramento, California.

The base binder will be tested for:

- Penetration, AASHTO T59
- Ring and Ball Softening Point, AASHTO T53
- G*/sin delta, AASHTO TP5

AASHTO T49 protocol will initially be used for recovering the base binder.

3.2.2.3 Mix Tests for Short-Term Properties

The three tests selected for use in this study are discussed below.

Mixing Test

TB 113 will be carried out on these systems and a matrix of proportions determined for acceptable mixes based on expert opinion.

The German mixing test will be carried out to determine the mix and spreadability indices. The measured mixing times from TB 113 will be used as the first cut for initial mixing and mixing to coating will be the mix index and the spreadability will be the time for stiffening to just before no mixing is achievable (see Figure 3-2).

The cohesion values that will be reported are the mix and spread indices. The mixes will be retested using different levels of additives and fillers to establish a range of values for control purposes.

This test will be repeated for four levels of environmental conditions:

- High temperature (35°C) low humidity (<50 percent)
- High temperature (35°C) high humidity (90 percent)
- Low temperature (10°C) low humidity (<50 percent)
- Low temperature (10°C), high humidity (90 percent)

The specification values may be adjusted and the mixes repeated with both TB 113 and the proposed German mixing test.

The acceptance criteria will be based on mixes with which the project team has experience and has identified for both TB 113 and the German test. The test will then be checked with a mix of known performance histories using other materials with which the team and advisory group have significant experience.

Cohesion Test

The short-term properties will be established using a modified TB 139. The mixing test study (mentioned above) will be used to select mixes for cohesion testing. Only acceptable mixes from the mixing test study will be used for this test program.

The basic levels already established in TB 139 will be used as a base point. The proportions will be chosen from above for acceptable mixes for mixing and spreading.

Initially, one mix of each surfacing type will be selected, as shown above.

- Ralumac micro-surfacing, Type III
- CQS-1h Slurry, Type III

The proposed modified TB 139 test will be performed under several sets of conditions, including:

- Compacted and un-compacted specimens
- Humidity, high (90 percent) and low (<50 percent)
- Temperature of cure, high (35°C) and low (10°C)
- Fully cured

Acceptance will be on mixes meeting both TB 139 and the proposed test.

Acceptance will be based on mixes that the project team has experience with at conditions identified for both TB 139 and the proposed test. The test will then be checked with a mix of known standard properties using other materials with which the team and advisory group have experience.

Abrasion Test

The abrasion resistance of successful mixes will be checked using similar curing and conditioning conditions using the French WTAT. Only samples cured to 24 hours will be used. Soak times of 1 hour and 6 days shall be used after the 24-hour cure. Acceptable levels of loss will be determined based on successful field mixes that the project team has experience with under the same conditions.

3.2.2.4 Procedure for Optimizing the Binder Content of the mix

The recommended procedure for optimizing the binder content of the mixture is described below.

- Take selected proportions from the mixes noted above and vary the emulsion content ±1 percent from optimum. These samples are fully cured so the additive and filler are “fixed” from the above noted mixes.

- Perform the French WTAT (at 1 hour and 6-day soak on fully cured samples).

- Conduct the loaded wheel test to determine excess asphalt at the temperature that corresponds to the project traffic profile: heavy, 35°C; moderate, 25°C; and low, 15°C.

- Select the optimum binder content by comparing the loss versus binder content from the wet track abrasion test and the binder content versus pick up from the loaded wheel test.

- Use the minimums as established from the test for abrasion loss and maximums from the test for sand pick up.

The test will then be checked with a mix of known standard properties using other materials with which the team and advisory group have experience.

3.2.2.5 Long-Term Mix Properties

After selecting the best mix from the short-term test methods noted above, the mix will be tested for the following long-term performance properties:

- Abrasion resistance
- Water resistance
- Deformation

Abrasion Resistance

This property will be measured using the modified TB 100 test (French WTAT) using fully cured specimens, soaked for 6 days, under project specific environmental conditions.

Water Resistance

The French WTAT abrasion test will be run on the final mix design by soaking for 6 days at a temperature of 35°C and comparing the loss to that of a 1-hour soak and express this as a ratio. This information will be compared to the results of an existing mixture in order to determine the appropriate specification limits. The test will then be checked with a mix of known standard properties using other materials with which the team and advisory group have experience.

Deformation

The propensity to rut will be measured using the Asphalt Pavement Analyzer (APA) at a temperature of 35°C. The rate of rutting will be determined from a standard successful rut resistant mix using the selected aggregates and the Ralumac emulsion. The test will then be checked with a mix of known standard properties using other materials with which the team and advisory group have experience.

Crack Resistance

Cracking resistance is not considered a performance property of slurry and micro-surfacing mixtures. No specialized crack testing is proposed.

3.2.3 Equipment Needs

It is estimated that the following equipment needs and modifications will be necessary in order to complete the above work.

German Mixing Test Apparatus

The project team can arrange to have the equipment donated to the project, but if that is not possible, one will need to be purchased. The cost is estimated at $6,000.

ISSA TB39, Cohesion Tester

Modifications to this test will be necessary to accommodate temperature and humidity controls. The cost is estimated at $15,000.

3.2.4 Estimated Cost and Schedule

Based on the work plan described in the previous sections, it is expected that the activities scheduled under Phase II will be accomplished within time and proposed budget. An updated cost estimate for the Phase II effort is provided in Table 3-5 and the revised schedule is shown in Figure 3-7.

TABLE 3-5 Test Factorial and Updated Cost Estimate for Phase II Activities

Test Factorial	
Binders: Koch Ralumac, CQS-1h VSS	2
Aggregates: Table Mountain, Lopke Gravel	2
Unknown	1
Total Mixes	**5**

Cost Estimate for Testing		
Items	**Cost Per Item, $**	**Total, $**
Binder	1,400	2,800
Aggregate	2,100	8,400
Mix	44,720	223,600
Total Costs		**234,800**

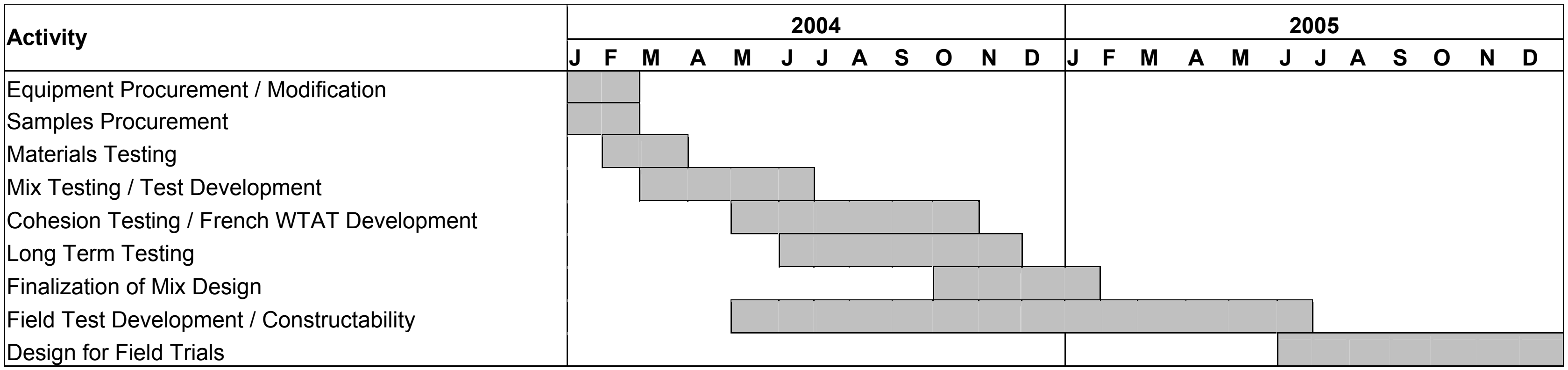

FIGURE 3-7 Updated performance schedule of Phase II activities

3.2.5 Conduct Ruggedness Testing

3.2.5.1 Purpose of the Experiments

The overall purpose of a *Ruggedness Testing Experiment* is to evaluate the sensitivity of the output of a particular test to allowable variation in the test conditions.[13] For example, consider a simple hypothetical test method involving a device that can be used to measure the sodium content in a given sample of water. Under the range of typical test conditions, the result of this test may be sensitive to the variability of such factors as the temperature of the water, the amount of solar radiation, and the level of other chemicals and contaminants in the water. A ruggedness test for this device (test method) would involve the design and conduct of an experiment to determine the overall effect of the variation of these other factors on the primary test result (i.e., the sodium content of the water). If the test result is unaffected by the variation of the other factors (within their typical ranges), then the test method is considered *rugged*.

Obviously, *ruggedness* is a desirable attribute for all test methods, including those that will be used for slurry/micro-surfacing mix design. For any given test method associated with the mix design process, the evaluation of ruggedness can best be done by performing all of the tests in one laboratory, so that there is no laboratory effect to consider. The results from the ruggedness experiment will then provide a basis for evaluating the effect of test conditions under later *round-robin testing* of the test methods.

3.2.5.2 Statistical Model

For each of the test devices/methods undergoing the ruggedness testing, the *statistical model* that will be used to evaluate the effect of the variability of test conditions will be a simple linear model. This means that each of the condition variables (X1, X2, X3, and so on) will be evaluated as if they have a linear effect on the dependent variable (i.e., the value of the test result). Considering the overall purpose of the analysis, it is reasonable to assume that the sensitivity can be characterized and evaluated using first order (linear) effects (see Figure 3-8a). Although the relationship may have some curvilinearity, the linear model does capture the primary effect in the region between the low and high levels of the condition variable.

The one case where this assumption can break down is the situation where the condition variable has a quadratic effect and the low and high levels of the condition variable are set at points where they have a near-equal effect on the test result (see Figure 3-8b). In this case, the model would indicate a near zero effect, when the effect is actually significant. Considering the small likelihood of this happening versus the cost of expanding the experiment design to test for it, the project team recommends erring on the side of minimizing the cost of testing.

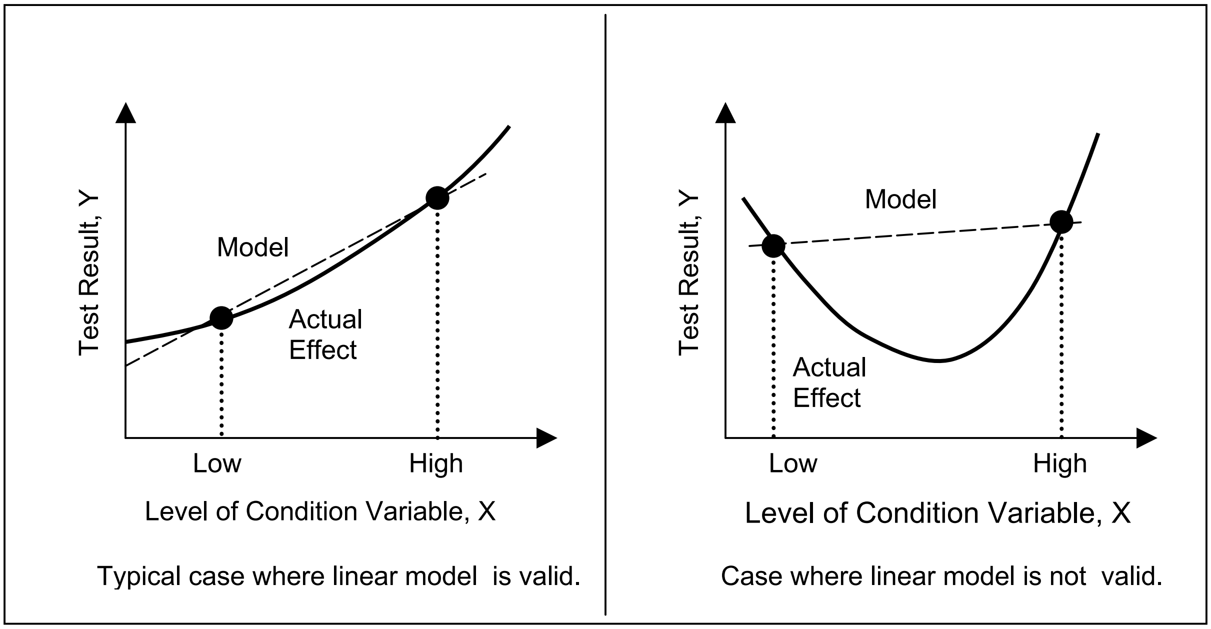

Figure 3-8a **Figure 3-8b**

FIGURE 3-8 Examples of relationships between test result and condition variable

3.2.5.3 Choice of Experimental Plans

The experimental plans for ruggedness testing are either a *fractional factorial* or a *Plackett-Burman.* [14] These designs are similar (sometimes the same) in that they allow for the fitting of a first-order model with a minimum of experimental points. For these experiments, there will be only two levels for each of the condition variables. The low and high values will be selected to cover the normal range of the condition variables. The number of replications (duplicates of select test combinations) will be determined so that the estimated coefficients in the model will be sufficiently precise for the evaluation of their importance. The number will depend upon the range of these condition variables and the standard deviation of the measurement device. This critical standard deviation will be available either from the preliminary testing of a new device or from the estimates from earlier testing of the known devices. In all cases, at least three replications will be made with each device.

3.2.5.4 Proposed Experimental Plans

Following is a description of the experimental plans and designs for ruggedness testing of the six different test methods associated with the new mix design method. For each test method, a certain number of tests must be performed in order to determine its ruggedness. The individual tests performed for each test method are completed according to a statistically designed experiment involving a) a specified number of tests conducted in a random order prescribed by the experiment design, and b) two (high and low) levels of the condition variables. For each test method, the condition variables are identified as individual independent variables, in accordance with the general form of the *simple linear model*. The levels of each of the condition variables for an individual test observation (Obs.) are coded as follows:

- -1 for low levels
- +1 for high levels

These levels will be far enough apart for the estimated coefficients to be precise, but close enough for the linear model to provide a reasonable fit, two conflicting requirements.

Following are the planned experiment designs for each test method:

- Mix/short term mixing test
- French WTAT short term test
- Cohesion test
- Sand pick-up test
- French WTAT long term test
- APA test (minimal testing for rutting only)

Mix/Short Term Mixing Test

For this test, the condition variables are:

- X1 - Filler Proportion
- X2 - Additive Proportion
- X3 - Water Content
- X4 - Emulsion Content
- X5 - Temperature
- X6 - Humidity

With six condition variables, a Plackett-Burman design with three replications will be a good choice. If the replications are assumed to be run in 3 *blocks,* there will be 12 degrees of freedom for the estimation of the standard deviation of the measurements and this should provide the precision in the estimates of the parameters in the model as well as for their standard deviations.

A Plackett-Burman design for the six condition variables associated with this test method is given below.

Obs.	X1	X2	X3	X4	X5	X6
1	+1	+1	+1	-1	+1	-1
2	-1	+1	+1	+1	-1	+1
3	-1	-1	+1	+1	+1	-1
4	+1	-1	-1	+1	+1	+1
5	-1	+1	-1	-1	+1	+1
6	+1	-1	+1	-1	-1	+1
7	+1	+1	-1	+1	-1	-1
8	-1	-1	-1	-1	-1	-1

French WTAT Short Term Test

For this test, the condition variables are:

- X1 Cure Time
- X2 Cure Temperature
- X3 Humidity of Cure
- X4 Test Time (Abrasion Time)
- X5 Test Temperature
- X6 Duration of Test

There is another condition variable, *Compaction* or *Not*, but this is not a variable for which its value is to be controlled as is the case for the other condition variables whose effects are being studied. If it is known that the effects of the above six condition variables do not depend strongly upon the compaction of the materials, then this experiment could be done with just one condition of compaction. If that is not known, then separate experiments with compaction and without compaction must be carried out. Otherwise, the experiments will be the same and the same as the Plackett-Burman experiment given for the Short Term Mixing Test, with three replications of selected combinations. There will not be an X7 variable, but the other six variables will be as given.

Cohesion Test

For this test, the condition variables are:

- X1 Cure Temperature
- X2 Cure Time
- X3 Cure Humidity

Again the condition variable, *Compaction* or *Not*, may need to be considered in the same manner as described in the Section above. Three replications of a half replication of a 2-cubed factorial will be used for this experiment. One such plan is given below with the coded values for the conditions:

Obs.	X1	X2	X3
1	-1	-1	+1
2	-1	+1	-1
3	+1	-1	-1
4	+1	+1	+1

Sand Pick Up Test

For this test, the only condition variable is the temperature of the preconditioning of the sample. This will be either 25º or 35ºC, and the robustness will be done separately for each of these values. Thus, for example, for the 35ºC, two temperatures of 33º and 37ºC may be selected and with five independent measurements at each of these temperatures, the effect of the temperature could be estimated so that the limits for the future could be determined. The same would be done for the 25ºC, but with tighter margins about the 25ºC.

French WTAT Long Term Test

For this test, the condition variables are:

- X1 Soak Time
- X2 Duration of Test
- X3 Temperature of Test Water

With the three condition variables, the same experiment as described for the Cohesion Test will be done.

APA Test (For Rutting Determination Only)

For this test, the condition variables are:

- X1 Temperature of Test
- X2 Duration of Test

With only two condition variables, three replications of a full 2-squared factorial experiment will be made. These will be done in a completely randomized manner so that there will be nine degrees of freedom for the estimation of the standard deviation of the error term. The plan, replicated in a random fashion, will be with coded variables:

Obs.	X1	X2
1	-1	-1
2	-1	+1
3	+1	-1
4	+1	+1

3.2.5.5 Randomization Requirements

It is essential that the experiments be carried out in a randomized order so that there will be a valid estimation of the true experimental error standard deviation as well as the precise estimation of the effects of the condition variables. Randomization will probably make the conduct of the equipment less efficient; however, it is necessary to properly address ruggedness. This will be done by the project team using the procedure specified by the project statistician.

3.2.5.6 Selection of Levels for the Condition Variables

It is important to keep careful records of all early experimentation with the testing devices so that a good preliminary estimate for their variability will be available. This will enable the project statistician to assist in the choice of the low and high levels of the condition variables in the *Ruggedness Experiment.*

3.2.6 Prepare Phase II Report

At the conclusion of this Phase of the study, a draft report will be submitted to Caltrans and the Study Panel for review and comments. Based on the review comments, a final report documenting all the activities of Phase II will be prepared.

A tentative outline for the Phase II report is given in Table 3-6.

TABLE 3-6 Draft Outline for Phase II Report

1.0	Introduction
	Background
	Objectives
	Scope
2.0	Development of Preliminary Mix Design Procedure
	Revisions to the Mix Design Procedure
	Development of Lab/Field Tests and Methods
	Construction Methods and Equipment
3.0	Ruggedness Testing
4.0	Conclusions and Recommendations
5.0	References

3.3 SUMMARY OF EXPECTED DELIVERABLES

Phase II of this project will have the following deliverables:

- A recommended mix design procedure.
- An evaluation of promising test methods.
- New and revised test methods to determine constructability (short term) parameters, optimum binder content, and long term performance indices.
- Recommended field tests for Quality Control/Quality Assurance (QC/QA) purposes.
- Ruggedness testing results from all of the recommended test procedures.
- New and revised test methods in AASHTO format.

3.4 REFERENCES

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CHAPTER 4 PROPOSED WORK PLAN FOR PHASE III

The proposed work plan is still considered a preliminary one and will be updated when the results of the Phase II study are finalized. It represents the best estimate of what will be needed to fulfill the contract requirements.

4.1 PURPOSE OF PHASE III STUDY

The purpose of Phase III is to validate that mixes designed in the laboratory, using the new and revised procedures as outlined in Phase II, can actually be built in the field. This chapter presents the proposed Work Plan to complete the following tasks, as outlined in the original proposal:

- Develop guidelines and specifications for the proper use of slurry and micro-surfacing.
- Develop a workshop training program that includes a pre-construction module to educate and inform agency, contractor, and material supplier personnel of the new design procedures and constructability issues.
- Construct and monitor pilot projects for the validation effort.
- Revise the procedures or the training program based on test section field performance.
- Prepare a Final Report documenting all the activities throughout the project.

4.2 TASK 1: DEVELOPMENT OF GUIDELINES AND SPECIFICATIONS

During this phase of the work, the project team will develop guidelines that can be used by both contractor and agency personnel that will aid them in the proper selection of projects and the appropriate use of these treatments. For example, the guidelines for proper project selection will address issues such as type and condition of the existing pavement. These treatments are not effective if placed on pavements in poor to bad condition. Additionally, the project team will address the differences between the two slurry systems and provide guidance where each will meet expected performance expectations. For example, if quick return to traffic and friction are important functional characteristics desired by the agency, the use of micro-surfacing may be preferred over slurry.

The guidelines will also address constructability issues that need to be considered during the placement of these techniques. This will include mixing, wetting, and adhesion at the placement site as well as techniques to preclude segregation of the mix and homogenous spreading of the mix over the pavement surface.

Guidance will be provided to both agency and contractor personnel regarding the things to evaluate for proper curing characteristics of the emulsion. It is also important that identification be made of those characteristics that are of utmost importance in assuring the long-term performance of the mix. This will be dependent on the quality and reproducibility of the mix design and the condition of the existing pavement.

The team will develop the necessary specifications for both techniques. Working with existing specifications from agencies that have a great deal of experience with these systems as a starting point, we will include the new test methods and other appropriate sections in the specifications that we prepare.

4.3 TASK 2: DEVELOPMENT OF THE TRAINING PROGRAM

Under this task, the Fugro team will develop a comprehensive training program as the principal aid in the implementation of the new slurry/micro-surfacing mix design procedure. The program will include two primary training elements:

- A 1.5-day course designed to educate State highway agency personnel (at several levels), contractor personnel, and material suppliers on the technology and overall application of the new mix design procedure.

- A 1-hour presentation module that can be used to appraise inspectors and contractor personnel of the required new/improved construction procedures that have come about as a result of the new mix design procedure.

These two components will be treated as separate, but complementary, sets of training materials. A more detailed discussion of the development plans for each is provided below.

4.3.1 Slurry/Micro-Surfacing Mix Design Training Course

The training course to be developed under this effort will be designed to provide basic training on the development and application of the new mix design procedure. The training materials, as discussed in greater detail below, will include a Reference Manual, a set of training course visual aids (in electronic format), and an Instructor's Guide. The course will be designed for presentation over a 1.5-day period and will include two workshops. In developing the workshops, the goal will be to incorporate "hands-on" exercises that not only advance the learning, but help generate some enthusiasm and interaction among the participants, as well.

The materials for this course will be developed to be compatible with National Highway Institute's (NHI's) Guidelines for Training Materials because the NHI has set the standard for training materials.

4.3.1.1 Reference Manual

This manual will be a detailed, stand-alone document that covers all the key aspects of the new mix design procedure. It will be referenced throughout the course to help familiarize the participants with the contents and improve its use as a technical resource. Table 4-1 provides an outline of the manual as it is currently envisioned.

Technical leadership for this effort will be supplied by Jim Moulthrop. The key staff that will participate in its development include Glynn Holleran, Dragos Andrei, Steven Seeds, and David Peshkin.

TABLE 4-1 Draft Outline for Reference Manual

Section	Title/Description
1	Introduction • Background • Slurry/Micro-Surfacing Overview • Objectives and Scope of Manual
2	Project Selection Criteria
3	Pre-Construction Requirements
4	Specifications
5	Mix Design Criteria • Binder Requirements • Aggregate Requirements • Blending Requirements
6	Test Methods and Procedures • Framework • Mechanisms • Significance of Test Variables • Protocols
7	Construction Considerations and Limitations • Project Geometry • Weather Limitations
8	Construction Operations • Surface Preparation • Equipment and Calibration Requirements • Mix Design Verification • Stockpile Management • Troubleshooting • Inspection and Workmanship Requirements
9	QC/QA Requirements • Pre-Construction and Construction Testing Requirements • Frequency and Type of Test
10	Troubleshooting
-	References
-	Appendices • Test Methods • Specifications

4.3.1.2 Visual aids

Visual aids are required to present the training course material in a clear, consistent, and organized fashion. They will be prepared in electronic format using Microsoft PowerPoint®. This is a standard tool for NHI training courses and is very effective for both preparation and presentation of visual aids. Where appropriate, animation will be included in certain slide images to either emphasize certain points or provide an additional aid in understanding the message. Video clips of certain processes will also be included where they can provide the most benefit.

The organization of the course will closely follow that of the Reference Manual. Each section of the report will be translated into a training module with a presentation length ranging from 20 to 90 minutes, depending on the topic (see preliminary agenda in Table 4-2). In addition, two workshops will be prepared. A hands-on workshop involving the use of the different types of laboratory equipment will developed for conduct on the afternoon of the first day of training. The second workshop will be prepared in a game format (such as Jeopardy) to test learning and emphasize key points relative to the slurry/micro-surfacing construction process. It will be conducted during the morning of the second day of training.

TABLE 4-2 Preliminary Agenda for 1.5-Day Training Course

Day		Module	Title
1	AM	1	Course Overview
		2	Introduction to Slurry/Micro-Surfacing
		3	Project Selection Criteria
		4	Preconstruction Requirements
		5	Mix Design Criteria
	PM	6	Test Methods and Procedures
		7	Laboratory/Mix Design Workshop
2	AM	8	Construction Considerations and Limitations
		9	Construction Operations
		10	QC/QA Requirements
		11	Construction Workshop
		12	Summary and Closing Remarks

4.3.1.3 Instructor's Guide

The Instructor's Guide will be developed to provide detailed assistance to the instructor for the successful presentation of the training course. It will contain the following information:

- General Introduction (title page, table of contents, general course information, learning objectives, description of target audience, assumed course prerequisites, class schedule, key technical references, and sources of additional information).

- General Training Course Set-Up and Wrap-Up Procedures (preparatory activities, host agency interactions, room set-up, and pre- and post-workshop housekeeping items).

- Annotated Outline by Session (including learning objectives, key discussion points, answers to typical questions, time allotments, areas to reduce if time becomes an issue, copies of visual aids with annotations, and associated workshops or other learning evaluation/application methods).

David Peshkin will take the lead in developing the visual aids and the Instructor's Guide. Development assistance will be provided by Steve Seeds and Dragos Andrei. Jim Moulthrop will serve in both an advisory and review capacity.

4.3.2 Pre-Job Training Module

It is anticipated that this project will result in several significant modifications to the slurry/micro-surfacing construction processes as well as mix design procedures. Consequently, the purpose of this effort is to develop a pre-job training module, which will include a section on project safety, so that the "must know" information can be shared with agency and contractor personnel. This information will be extracted from the Reference Manual and a stand-alone document prepared for presentation and discussion during a meeting (similar to a pre-construction meeting) that will be held prior to the beginning of a slurry surfacing or micro-surfacing project. In addition, an easy to use, pocketsize guidebook will be prepared so that both agency and contractor personnel can take it into the field.

Jim Moulthrop will oversee and participate heavily in this effort. He will be assisted by Dragos Andrei and David Peshkin.

4.4 TASK 3: CONSTRUCTION OF PILOT PROJECTS FOR FIELD VALIDATION OF DESIGN PROCEDURES

The purpose of this work plan is to develop guidelines for the construction and evaluation of test sections for the validation of slurry seal and micro-surfacing mix design procedures. These guidelines indicate the type of equipment used and evaluation of the construction of test sections. A factorial for the determination of the site locations including test section layout has also been developed. Finally, a monitoring plan has been developed to determine constructability, and both short-term and long-term performance of the test sections.

The LTPP program developed a study to determine the long-term performance of various maintenance treatments.[1] Seven States participated in the construction of these test sections. The layout of these sections along with their site selection provided valuable information for the economical evaluation of the test sections. A similar plan is proposed for the validation of the slurry and micro-surfacing mix design procedure.

Fortunately, there has been widespread support for this study, which includes agencies from the States noted in Chapter 1. It is hoped that additional States may add their support before the conclusion of this study. These States provide a diverse set of climatic conditions ideally suited for this study. Their support in sponsoring and constructing test sections for slurry surfacing and micro-surfacing will greatly benefit this study.

4.4.1 Identification of Test Sections

4.4.1.1 Site Selection

Many factors affect the performance of slurry seal and micro-surfacing projects. These include climate, traffic, condition of the existing pavement prior to the application, workmanship, and the mix design. A matrix factorial considering each of these variables has been developed and is noted in Table 4-3. Consideration was given to the cost of constructing these test sections during the development of this factorial. It is important to consider each of the factors affecting performance to provide the team with the proper information to perform a validation of the procedures.

TABLE 4-3 Site Selection Matrix Factorial

Traffic	Surface Type	Climatic Region			
		Wet-Freeze	Wet-No Freeze	Dry-Freeze	Dry-No Freeze
High >25,000 ADT <10 m ESALS**	HMAC	*(1,2)	*(1,2)	*(1,2)	*(1,2)
	PCC				
Moderate >10,000<25,000 ADT >4<10 m ESALS	HMAC	*(1,2)	*(1,2)	*(1,2)	*(1,2)
	PCC				

*1-Coarse
*2-Coarse (rut, or level-up)
**Equivalent Single Axle Load

An examination of the site conditions prior to selection must be conducted to insure uniformity among the test sections. The first step is to insure that the site is long enough to accommodate the number and length of test sections to be included in the site. Particular attention to entrance and exit ramps should be taken to insure uniform traffic among the test sections. It is preferable that the agencies avoid roadways that have sharp turns and superelevation in order to mitigate the interaction of the tire and the pavement between different test sections. It is recommended that the test sections be located on a relatively straight roadway with uniform vertical grade. The existing condition of the pavement (surface distress) should also be determined. It is recommended to select pavements with little or no distress. However, sites with limited distress will be accepted as long as the site has uniform conditions (raveling, bleeding, transverse cracks, etc.). Distress surveys using the LTPP Distress Identification Manual (DIM) shall be conducted on all sites prior to placement of the treatments to document the pavement condition.(2) This manual contains survey sheets and specific instructions on conducting these types of distress surveys.

Ride quality has been shown to impact the rate of deterioration of pavements. It is recommended that the surface of the pavement be smooth and provide an excellent ride level to reduce the effects this may have on individual sections within a test site. As a target, the existing surface should have a prorated IRI of less than 158 mm per 1,000 m (100 in. per mile) as measured by a calibrated profiler.

A site will be required in each of the four climatic regions. The current project States provide this diversity of climate regions. The four climatic regions used by the LTPP program were

Wet-Freeze, Wet-No-Freeze, Dry-Freeze, and Dry-No-Freeze. These regions were determined by the amount of average annual precipitation and duration of freezing temperatures during an average year. The type of climate has a significant impact on the selection of the mix. In warm and dry climates, the rate of evaporation is greater and slow setting emulsions are desired. The opposite is true of wet and cold climates. The rate of curing can be altered by the amount of water, cement, emulsion, and set control chemicals. The four climatic regions will provide an opportunity to apply different mix designs using the new recommended procedures.

The effects of traffic also have an impact on the rate of deterioration. Traffic loadings may be determined in many different ways; unfortunately, there is no consistent national traffic loading reporting scheme. Many States do not utilize a consistent traffic loading procedure. The most prevalent way to express traffic loadings is the Equivalent Single Axle Load (ESAL), which is based on Average Daily Traffic, Percent Trucks, Truck Factors, and other conditions. Another way is to express traffic applications as Average Daily Traffic (ADT) with a certain percentage of trucks. Other States use a Traffic Index based on ESAL values. Slurry seals and micro-surfacing are preventive maintenance treatments and are not used as enhancements to the structural capacity of the pavement. Because ESAL values are used primarily for the structural design of pavements and utilize an ADT and percent trucks, the expression of ADT and percent trucks is recommended to express traffic applications.

Table 4-3 presents the recommended matrix factorial for site selection. The amount of traffic for the factorial has been divided into two levels: high and moderate. The high traffic level ranges from 25,000 ADT and above (>10 Million ESALs). The moderate traffic level ranges from 10,000 ADT to 25,000 ADT (approximately 4-10 Million ESALs over 20 years with 10 percent trucks).

The variation of the type of subgrade soil and base materials (and their properties) between different sites will have an effect on the structural performance of the roadway. The costs associated with sampling and testing these materials at each site location is considered prohibitive. This would also burden the participating State DOTs with additional responsibilities. Therefore, this sort of sampling and testing will not be undertaken.

The primary focus of this study will be on the constructability of the recommended mix-designs and their performance compared to existing mix design procedures or various maintenance treatments. It is not recommended that subgrade soil and base types be included in the site selection. These treatments will be placed within the same site location and the structure should be approximately the same. If changes in pavement type or structural design are identified, the site should be adjusted to eliminate the presence of multiple pavement structures. The structural capacity of the pavement is important in determining the life span of the pavement. It is recommended that only those sites with sufficient remaining life (five years) be used for this study. This should prevent the need for maintenance and rehabilitation activities prior to completing the study.

4.4.1.2 Test Section Layout

The section layout will depend on the number of test sections desired for the study. As a minimum, the sections should include a control section without treatment and a slurry seal or micro-surfacing test section. This will provide validation of the constructability of the recommended mix design as well as the effect of the treatment on extending the existing pavement's life. However, this type of experiment does not allow a comparison of the improvement of the recommended mix design to existing mix designs or other treatments. Multiple treatment sections (e.g., slurry seal and micro-surfacing systems with different binders) along with the control are recommended to obtain the amount of information necessary for a complete evaluation and validation.

Multiple test sections using micro-surfacing may be placed using different types of polymers (e.g., natural rubber, synthetic rubber latex [SBR], or various combinations). It is recommended that a section using the ISSA design procedure be placed along with one of the recommended design procedures to determine the long-term performance of each type of mix design. The number of treated sections will depend on the results of the Phase II study and the desire of States to include supplemental sections to evaluate additional materials/treatments. Each treatment will be placed according to the construction guidelines described in this work plan. The recommended length of the test sections will be determined by the project team with approval from the panel and will be a minimum of 152 m (500 ft) and a maximum of 305 m (1,000 ft). The length of each test section will remain constant for each site in this study.

4.4.2 Construction Guidelines

The construction guidelines to be developed are intended to insure proper placement of the material. Direct discussions between the teams, the contractor, and the participating State agency will be held prior to construction and will be part of the training program outlined in Section 4.3. This interaction is critically important for developing the participants' necessary understanding of the objectives of the experiment and the need for cooperation in adhering, as much as possible, to the requirements outlined in this report.

Many of the problems encountered with slurry seal and micro-surfacing can be attributed to improper placement of the material. These problems include the field conditions at the time of placement (i.e., wet surface, debris present, and temperature). The LTPP program was able to use of the same crew and equipment in the SPS-3 studies: HMAC Maintenance Treatments.(1) It would be preferable for the same crew, equipment, and materials (aggregate and emulsion) to be used to apply all treatments in this project in order to reduce the impact of variation between treatment locations. However, due to the extreme effort of mobilizing the same crew and equipment to each State, this is cost prohibitive.

To account for the variables represented by differing crews and equipment, documentation on the type of equipment and source of materials is recommended to record the potential impacts these may have on the performance of the treatment. The project team has provided a plan, discussed below. Forms to obtain data on the lay down procedures are provided in Appendix G.

4.4.2.1 Pre-Construction

All cracks that are greater than 6 mm wide (0.25 in) should be sealed prior to application of the treatment. It is not anticipated that patching will be required because of the pre-qualifying condition of the test sites. If patching is required, it must be performed prior to the distress survey. The site conditions prior to construction will be recorded and will include the following:

- Pavement Distress using the LTPP DIM[(2)]
- Type of Surface Material and Construction History (age)
- ADT and Percent Trucks
- Climate
- QA Procedures Developed in Task 1
- Calibration of Equipment

Prior to construction, the pavement must be in a dry condition and free of debris.

4.4.2.2 Construction

The following construction guidelines must be followed:

- The treatment mix design can be placed only after the contractor has satisfactorily demonstrated proper placement procedures on non-test section locations.

- All transverse construction joints must be placed outside the test sections (e.g., within the transitions between test sections).

The distance between the transition areas must be sufficient to allow changes in materials during construction. The distance is required to accommodate changes in material type in a manner that will reduce the influence on the properties of the finished pavement. Each test section will have a minimum of 30 m (100 ft) before and after the monitored length to provide sufficient production to develop consistency after changes in materials.

The mixture for the treatment will be documented using the forms in Appendix G, which include the type and quantities (rates) for each of the following:

- Polymer-modified emulsified asphalt cement
- Well-graded crushed mineral aggregate
- Mineral filler (normally portland cement or lime)
- Water
- Other mixing aid additives (normally emulsifying agents)

The project team shall provide the mix design information to the contractor and agency prior to the beginning of the project.

The equipment used for the application of the treatment shall also be documented using the forms in Appendix G, which will contain the following information:

- Type of paving equipment (continuous, truck-mounted)
- Type of spreader box

The breaking and curing rates of the treatment will be collected and entered on the Equipment Form provided in Appendix G.

An agency that desires to participate, but finds it necessary to deviate from some of the guidelines described in the report, should review these deviations with the research team. The team will assess the implications of these deviations on the study objectives. If the implications of the non-compliance appear minimal, the deviations will be accepted; if the implications appear to represent a major impact, the team will suggest alternatives for consideration by the participating agency.

4.4.2.3 Post-Construction

It is recommended that the test sections be allowed to cure properly prior to the application of traffic loadings to prevent premature damage. Evaluations of the test sections will be conducted immediately after construction, prior to opening the site to traffic one month after construction, and one year after construction. It is important that the sections be marked with tape, paint, or placards to identify the test sections. It is also recommended that the exact section locations be obtained using Geographical Positioning Systems (GPS), route, milepost, or other reference information. A section identification code will be developed to identify individual sections in the study. The evaluations of these test sections will be described in detail in the following sections.

4.4.3 Pavement Evaluation

Each pavement evaluation before, immediately after, and one year after construction, will consist of a detailed survey of the existing pavement distress using the LTPP DIM. The post construction surveys will also include comments of any abrasion, delamination, drag marks by the spreader box, wash boarding, and measurements of surface texture and noise. Segregation and flushing are identified in the LTPP DIM.

A survey form has been provided in Appendix G that summarizes the distress information obtained from the field. The amount of rutting will be measured with a 1.8-m (6-ft) straight edge every 15 m (50 ft) within the test section. If a high-speed profiler is used having five or more sensors to obtain ride quality information, the rutting will be obtained from this information. The texture will be determined using sand patch or other accepted test procedures. After the test section is open to traffic, the noise level will be determined from a safe distance from the pavement edge (edge of shoulder) if the agency has this type of equipment available.

If subgrade and base properties are still desired by the agencies, then a sampling and testing plan will be developed to accommodate the collection of these data. Structural testing using a Falling Weight Deflectometer (FWD) may also be considered to determine the variability of the pavement structure throughout each of the test sites to determine the remaining service life or to identify if there are underlying structural problems. An evaluation of the costs associated with this additional data collection effort should be considered by the agency before adopting this effort because it is beyond the scope of this project.

4.4.4 Revision of Procedures and Training Programs

Based on the feedback from participants in the training modules and the contractor and agency personnel involved with the construction and evaluation of the pilot projects, adjustments will be made (where necessary) to the guidelines, specifications, and training programs to make them clearer and more "user friendly."

4.5 TASK 4: PREPARATION OF FINAL REPORT

Six months prior to the end of the project, work will begin on a final report that includes all of the activities conducted during the 4.5-year study. A draft will be submitted for review, comments will be noted, and changes to the draft will be made prior to submittal oft the final project report as outlined in Table 4-4.

TABLE 4-4 Draft Outline for Final Report

1. Introduction
    a. Background
    b. Objectives
    c. Scope
2. Development of Preliminary Mix Design Procedure
3. Development of Experimental Design and Data Collection Plans for Field Investigation
4. Summary and Analysis of Data from Pilot Section Construction and Performance
5. Calibration and Refinement of Mix Design Procedure
6. Training Program
7. Conclusions and Recommendations

4.6 ESTIMATED COST AND SCHEDULE

Based on the work plan described in the previous sections, it is expected that the activities scheduled under Phase III will be accomplished within the proposed time and budget. The cost estimate and performance schedule for Phase III are provided in Table 4-5 and Figure 4-1, respectively.

Note that the cost for Task III (Construction of Pilot Projects) does not include the cost of actually building the test sites or the associated QC/QA on the projects. Construction costs are estimated at $20,000 per 305-m (1,000-ft) test section.

TABLE 4-5 Cost Estimate for Phase III Activities

Task	Activity	Cost $
1	Development of Guidelines and Specifications	73,669
2	Development of Training Program	102,304
3	State Participation in Cost of Construction	< >
4	Construction of Pilot Projects	89,691
5	Preparation of Final Report	108,732
	Total	374,396

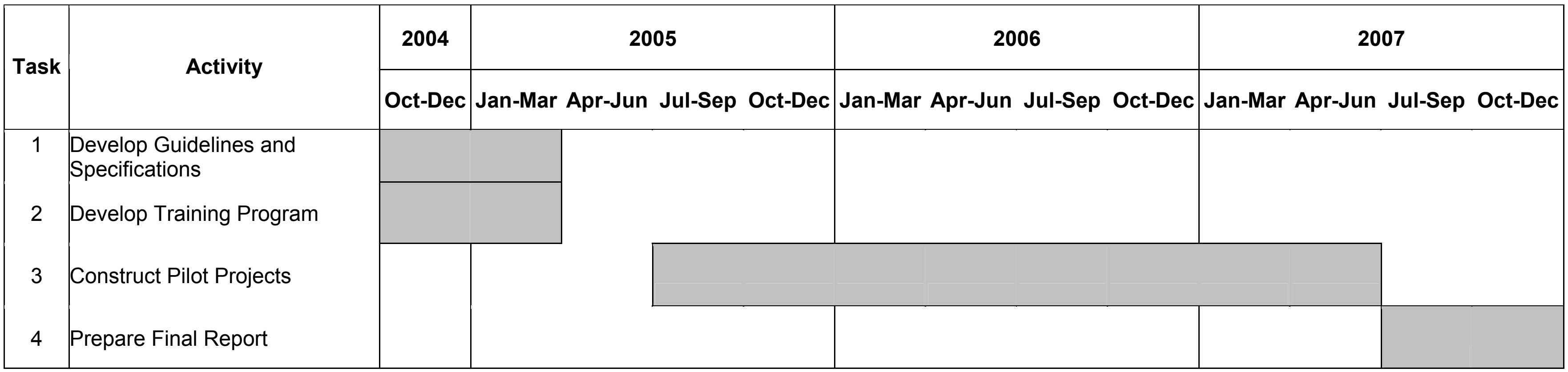

FIGURE 4-1 Performance schedule for Phase III activities

4.7 SUMMARY OF DELIVERABLES

Following are a list of the expected deliverables from Phase III:

- Develop Guidelines and Specifications
- Develop Training Program
- Construct Pilot Projects
- Conduct a Pre-Construction Training Program
- Revise the Procedures based on field performance
- Revise the Training Program as necessary
- Develop a Final Report

4.8 REFERENCES

1. SPS-3 Construction Report, SHRP Contract H-101, Brent Rauhut Engineering, SHRP Southern Region Coordination Office, Strategic Highway Research Program, Federal Highway Administration, Washington, DC, January 1991.

2. *Distress Identification Manual for the Long-Term Pavement Performance Program*, FHWA-RD-03-031, Federal Highway Administration, Washington, DC, June 2003.

CHAPTER 5 PRELIMINARY FINDINGS

Chapter 5 presents the preliminary findings from the Phase I effort in the following areas (which provide the basis for the execution of the work plan under Phases II and II):

- Literature Review and Surveys
- Laboratory Test Plan
- Field Test Plan

5.1 LITERATURE REVIEW AND SURVEYS

Based on the literature review and the results of the agency, industry, and advisory surveys, the following observations are made:

1. The existing mix design methods for slurry and micros are very limited. The most widely used are those developed in the 1960's and 1970's, and they are empirical. This limits the ability to design successful mixes for a broad range of conditions. Very limited new information was obtained from overseas.

2. Both the ASTM and ISSA mix design methods clearly state that the methods described should be used only as a guide. Therefore, a more exact method is needed to provide successful mix designs, based on performance-related tests included in the design method rather than relying heavily on the experience of the construction crew with these types of treatments.

3. All test methods investigated need improvement. Most are vague in describing the minimum number of replicate tests, the number of test specimens, and the range of conditions to be used with a specific test (e.g., range of variation in temperature, humidity, soaking time). In standardized methods, these details are available for every laboratory test used as part of the design procedure.

4. The test specimen geometry and method of preparation vary from one test to another. Ideally, all tests should make use of similar test specimens and several tests would be performed on the same test specimen.

5. In all tests, the aggregate particles larger than the No. 4 sieve are scalped off. Ideally, a larger test specimen should be used to maintain the original gradation of the mix in the test specimen.

6. The repeatability of all recommended laboratory tests should be determined. None of the existing test methods contain precision or bias statements.

7. The existing guidelines and specifications for the design and construction of slurry seal and micro-surfacing systems are very similar and do not need to be treated separately. The results of the field surveys indicate that the major user concerns

with these products are workmanship, control of mixing, and reflective cracking. New and improved guides and specifications are needed to address these concerns.

8. A single method for the design of both slurry seal and micro-surfacing would contribute to the simplification and clarification of the design and construction guidelines for these treatments. The new method must be related to the field performance of the treatment and be relatively easy to use and implement.

9. The great majority of the existing slurry seal and micro-surfacing field projects contain information on the short-term performance of these systems, but very limited or no long-term performance data is available.

10. User agencies should be educated about the purpose, mechanisms, and options of the products available for preventive maintenance. This will help them differentiate between failure and misuse of these treatments. It will provide them with a better understanding of the project selection process.

5.2 LABORATORY TEST PLAN

Test plans for the laboratory development of an improved mix design procedure and its eventual validation in the field were formulated. The development process resulted in the following recommendations:

1. The laboratory test plan will focus on developing test procedures to evaluate both short and long-term performance. Where possible, existing tests will be used. All tests should be related to field performance.

2. Tests should be performed at standard conditions as well as those actually encountered at the job site. Tests need to be developed to evaluate mixing characteristics, and short- term and long- term performance.

3. The tests to be developed must meet the following criteria:

    - Easy to use
    - Related to field performance
    - Repeatable
    - Easy to implement

The mix design method that results from this research must also be affordable.

The project team is cognizant of the key issues noted above and will address them when commencing work on Phases II and III.

5.3 FIELD TEST PLAN AND TRAINING

The purpose of the field test plan is to validate the mixes designed in the laboratory, using these new and revised procedures to determine whether they can actually be built and perform well. The validation process will be comprised of the following:

- Develop guidelines and specifications for the proper use of slurry and micro-surfacing.
- Prepare a training program, including a pre-construction module, to educate agency, contractor, and material supplier personnel on the new design procedures and constructability issues.
- Construct and monitor pilot projects for the validation effort.
- Revise the procedures or the training program as necessary.
- Prepare a final report documenting all the activities throughout the project.

Guidelines for the identification of test sections have been developed to include site selection and layout of the proposed test sections. The experimental matrix of sections developed for this evaluation includes climatic factors, traffic levels, and varying mix designs. Construction guidelines also have been developed to address pre-construction activities such as crack sealing and sweeping, and construction and post-construction activities. These activities include distress surveys performed both before and after construction, and at one year after construction, to provide performance information.

APPENDIX A BLANK QUESTIONNAIRES

CALTRANS PROJECT 65A0151
SLURRY AND MICROSURFACING MIX DESIGN PROCEDURES

QUESTIONS FOR AASHTO LISTSERVE RECIPIENTS

Please include any comments you might have with your answers. Use a separate sheet of paper if necessary.

You may forward this questionnaire to whomever you feel is appropriate in the interests of this project.

Your input is greatly appreciated. Thank you for your participation in this project.

0 Background Information
Name of Agency
Person Completing Survey
Telephone Number
Email Address

1 Do you currently use or plan to use slurry seals and/or microsurfacing systems on your roadway system?

☐ Yes – How much of each (approximately) have you used in the years noted below (please specify the units used)?

Year	**Slurry Seal, yd^2 or tons**	**Microsurfacing, yd^2 or tons**
2003		
2002		
2001		

☐ Plan to use in the future?

_____

☐ No – Is there a particular reason why?

_____

2 If you currently use these systems, do you expect to continue to use them? Please explain why:

☐ Yes _____

☐ No _____

3 What is your experience/expectations regarding the service life of slurry seals and microsurfacing systems (how long do you expect them to last)? Include traffic volume, intersection vs. mainline, and other details, if needed:

Service Life (years):	**Slurry Seals**	**Microsurfacing**
From Past Experience:		
Expected:		

Other Comments:

_____

4 Have you experienced any performance problems with slurry and microsurfacing systems during construction?

Frequency	**Slurry Seals**	**Microsurfacing**
Most often:		
Least often:		

5 Have you experienced any performance problems with slurry and microsurfacing systems after construction?

Frequency	**Slurry Seals**	**Microsurfacing**
Most often:		
Least often:		

6 Do you perform any QA testing and evaluation on these systems? Please explain:

☐ For microsurfacing:

_____

☐ For slurry seals:

_____

☐ No QA

7 Other comments:

_____

_____

Thank you for your participation. Please send the completed questionnaire by mail/fax/email to:

James Moulthrop, P.E.
FUGRO-BRE, INC.
8613 Cross Park Drive
Austin, Texas 78754

Phone (512) 977-1800
Fax (512) 973-9565
Email: jmoulthrop@fugro.com

CALTRANS PROJECT 65A0151
SLURRY AND MICROSURFACING MIX DESIGN PROCEDURES

QUESTIONS FOR ADVISORY PANEL CONTRACTORS

Please include any comments you might have with your answers. Use a separate sheet of paper if necessary.

You may forward this questionnaire to whomever you feel is appropriate in the interests of this project.

Your input is greatly appreciated. Thank you for your participation in this project.

0 Background Information

Name of Company
Person Completing Survey _____
Telephone Number _____
Email Address _____

1 Please indicate who designs your slurry seal and microsurfacing mixtures:
- ☐ Private testing laboratory
- ☐ Emulsion supplier
- ☐ Other: _____

2 What are the biggest areas of complaint from your customers?
- ☐ Service life
- ☐ Traffic time
- ☐ Adaptability to conditions
- ☐ Other: _____

3 Do the slurry seal and microsurfacing mix design provided to you satisfy your requirements in terms of being able to mix, place, and finish the system? Please indicate below (Yes/No):

	Slurry Seals	**Microsurfacing**
Mix		
Place		
Finish		

4 Do you make adjustments to the mix design in the field? Please indicate the reasons below:

☐ Adjustments to slurry seals:

______

☐ Adjustments to microsurfacing:

______

5 Have you encountered problems reproducing the laboratory mix design in the field?

☐ Yes, with slurry seal:

______

☐ Yes, with microsurfacing:

______

☐ No

6 Other comments:

______

______

Thank you for your participation. Please send the completed questionnaire by mail/fax/email to:

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8613 Cross Park Drive
Austin, Texas 78754

Phone (512) 977-1800
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Email: jmoulthrop@fugro.com

CALTRANS PROJECT 65A0151
SLURRY AND MICROSURFACING MIX DESIGN PROCEDURES

QUESTIONS FOR INDUSTRY PARTICIPANTS

Please include any comments you might have with your answers. Use a separate sheet of paper if necessary.

You may forward this questionnaire to whomever you feel is appropriate in the interests of this project.

Your input is greatly appreciated. Thank you for your participation in this project.

0 Background Information
Name of Company ______
Person Completing Survey ______
Telephone Number ______
Email Address ______

1 Do you design slurry seals and/or microsurfacing systems?

☐ Yes – What design method do you use?

______

☐ Plan To – What design method are you planning to use?

______

☐ No – Is there a particular reason why?

______

2 In what way is the design method you use or plan to use different from the International Slurry Seal Association (ISSA) Procedure?

☐ No difference

☐ Minor Difference – Please explain:

______

☐ Major Difference – Please explain:

______

☐ Don't Know – I am not familiar with the ISSA design procedure.

3 In the design method you use or plan to use, are there any test methods and/or procedures that need to be revised or eliminated?

☐ No

☐ Yes – Please list the test method(s) and explain why they should be revised or eliminated:

______

4 In the design method you use or plan to use, which mix design procedure/criteria relates to construction and/or long-term performance? Please explain why you think there is a relationship to construction and/or long-term performance.

☐ Construction:

______

☐ Long-term performance:

______

5 What types of complaints do you receive from your customers:

☐ Most often – Please list:

______

☐ Least often – Please list:

______

No complaints

6 What do you try most to control or allow for in field operations, and why?

______

7 Other comments:

______

______

Thank you for your participation. Please send the completed questionnaire by mail/fax/email to:

James Moulthrop, P.E.
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Austin, Texas 78754

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APPENDIX B SUMMARY OF RESPONSES

CALTRANS PROJECT 65A0151
SLURRY AND MICRO-SURFACING MIX DESIGN PROCEDURES

RESPONSES TO QUESTIONS FOR AASHTO LISTSERVE RECIPIENTS

Q1	**Do you currently use or plan to use slurry seals and/or micro-surfacing systems on your roadway system?**		
A1	**Yes**	•••••••••••••••	15
Quantities Used in Yd^2	Slurry Seal in 2001:		0
	Slurry Seal in 2002: 6,980,000; 10,000	••	2
	Slurry Seal in 2003: 6,220,000; 35,066	••	2
	Micro-surfacing in 2001: 773,642; 2,200,000; 704,000; 1,907,289; 153,100; 75,000; 285,814	•••••••	7
	Micro-surfacing in 2002: 997,673; 1,000,000; 203,980; 704,000; 1,779656; 760,000; 146,000	•••••••	7
	Micro-surfacing in 2003: 497,700; 70,400; 1,000,000; 46,424; 704,000; 1,816,029; 1,430,000; 82,000; 417,905	•••••••••	9
Quantities Used in Tons	Micro-surfacing in 2001: 19,200; 10,784;	••	2
	Micro-surfacing in 2002: 1,200; 7,000; 4,781;	•••	3
	Micro-surfacing in 2003: 18,000; 4,807;	••	2
A2	**Plan To**	••••••••••••••••	16
	Yes	•••••••••••••	13
	Limited	•	1
	Micro-surfacing as a warranted pavement treatment	•	1
	Micro-surfacing will continue to be used	•	1
	Best product to maintain and extend life of high volume highways	•	1
	Micro-surfacing is a treatment available but seldom used mostly due to cost	•	1
	Five projects scheduled for micro-surfacing in 2004 (30+ miles)	•	1
	100 – 200,000 yd^2	•	1
	Approximately 150, 000 yd^2	•	1
A3	**No**	•••••••	7
Particular Reason	Existing micro-surfacing is exhibiting severe potholes and deterioration of underlying AC results	•	1
	No success with slurry seals when tried a couple of years ago	•	1
	Prefer 1 inch HMAC overlays for thin surface treatments	•	1
	Slurry seals have not performed to expectations and Micro-surfacing is not cost effective	•	1
	Previous research by NJDOT recommended that slurry seals not be used on roads with AADT>10,000. All NJDOT roads have AADT>10,000.	•	1
	Slurry seals used by maintenance for transverse crack sealing but not as a surface treatment due to slow cure	•	1
Q2	**If you currently use these systems, do you expect to continue to use them? Please explain why:**		
A1	**Yes**	•••••••••••••••	15
Explain	Temporary rehab method and/or for purpose of temporarily increasing pavement friction	•	1
	Micro-surfacing good treatment for skid resistance, filling in ruts and pavement preservation	•	1
	Based on the good performance over several years	•	1
	Micro-surface can be used as a surface maintenance treatment	•	1
	Provides a relatively inexpensive new surface that renews friction and preserves underlying pavement from further environmental deterioration	•	1
	Good maintenance strategy for extending pavement life for roadways that do not require structural overlay but are exhibiting rutting or loss of friction	•	1
	The use of micro-surfacing will continue to grow and is usually used on higher volume roads > 10,000 AADT	•	1

	Excellent performance with micro-surfacing put down 5 years ago. Expecting 8 to 10 years of service life with wear and sealing factors. If road testing shows base to be in good condition, another micro on same high volume roadways is feasible	•	1
	Use expected to continue on appropriate projects	•	1
	Slurry seals and micro-surfacing are performing satisfactorily	•	1
	Micro-surfacing improves skid, thin lift seals cracks, extends pavement life	•	1
	Micro-surfacing will be used as a cost effective approach to the state's pavement preventative maintenance program	•	1
	Excellent results when used as a seal cost versus oil and chip at a similar price	•	1
	Found it to be a good alternative to seal coat for high traffic roads, subdivisions, villages and low traffic county highways	•	1
A2	**No**	•	1
Explain	Previous research by NJDOT recommended that slurry seals not be used on roads with AADT>10,000. All NJDOT roads have AADT>10,000.	•	1
Q3	**What is your experience/expectations regarding the service life of slurry seals and micro-surfacing systems (how long do you expect them to last)? Include traffic volume, intersection versus mainline and other details, if needed:**		
A1	**Service Life: Slurry Seals**	••••	4
From Past Experience:	No success, cracks and distresses show the same year after we applied it	•	1
	3 – 6 years	•	1
	3 – 5 years	•	1
Expected:	To retard distress for at least 2 years	•	1
	3 – 6 years	•	1
	3 – 5 years	•	1
	5 years	•	1
A2	**Service Life: Micro-surfacing**	•••••••••••••••••	17
From Past Experience:	3 – 5 years, Principal Arterial Functional Class and Lower	••	2
	2 – 5 years	•	1
	5 – 7 years	•	1
	4.6 years	•	1
	6 – 7 years	•	1
	Used to repair ruts in the wheel path in low-moderate volume roads	•	1
	4 – 12 years	•	1
	5 – 15 years	•	1
	First job was in 1999	•	1
	8 – 10 years	•	1
	5 – 8 years	•	1
	3 – 6 years	•	1
	Main Highway 20 million ESAL in 20 yrs, wet freeze: 1 year	•	1
	Main Highway 20 million ESAL in 20 yrs, wet no freeze: 3 years	•	1
	Main Highway 20 million ESAL in 20 yrs, dry freeze: 4 year	•	1
Expected:	3 – 5 years	••	2
	5 – 7 years	••	2
	5 years	•	1
	5 – 8 years	••	2
	6 – 7 years	•	1
	To defer distress for 5 years	•	1
	6 – 8 years	••	2
	10 years	•	1
	8 – 10 years	•	1
	3 – 6 years	•	1
	4 – 5 years	•	1
	8 years	•	1
A3	**Other Comments**	•••••••••	9
	Not recommended on Interstates, Freeways and Expressways	•	1
	Micro material which lasted 2 years had AADT of 11,000	•	1

	Durability dependent upon existing roadway and placement conditions and surface loading. Missouri experience is towards placing the surface on poorer existing surfaces instead of as a preventive maintenance treatment	•	1
	Experience extremely limited	•	1
	Past experience life is based on data from 1990 to present and from micro-surfacing until another action. Micro-surfacing condition may not have been reason for action. Service life up to 6 years at 7000 AADT on some sections. Majority of sections with AADT<3000 have 3 – 6 years service life	•	1
	Slurry seals utilized on secondary roads and some micro-surfacing done on lower volume primary roads	•	1
	Expected 4 to 5 years with good mix and quality placement	•	1
	Three projects micro-surfaced in 2001: 2 state highways and 1 interstate highway	•	1
	New to our department, trying it out, looking for alternatives to seal coats	•	1
Q4	**Have you experienced any performance problems with slurry and micro-surfacing systems <u>during</u> construction?**		
A1	**Frequency: Slurry Seals**	•••	3
Most Often:	Hard to control	•	1
	Mix issues – correct proportions of aggregate and asphalt	•	1
	Insuring lime feed is working	•	1
Least Often:			0
A2	**Frequency: Micro-Surfacing**	••••••••••••	12
Most Often:	Traffic control and adequate cure time	•	1
	Cure Time: 15%	•	1
	Contractor workmanship such as starting and stopping equipment creating undesirable joints	•	1
	Slow cure in cool humid conditions	•	1
	Emulsion quality control	•	1
	Sloppy edge lines	•	1
	Control of water added	••	2
	Poor aesthetics and operator training	•	1
	Poor Set up times	•	1
	Raveling	•	1
	Contractor testing of aggregate	•	1
	Mix issues – correct proportions of aggregate and asphalt	•	1
	Insuring lime feed is working	•	1
	Roughness due to screed problems and due to reflective cracks	•	1
	Loss of stone matrix in wheel path shortly after roadway opened to traffic	•	1
Least Often:	Roadway surface must be clear prior to placement	•	1
	Joints: 10%	•	1
	Temperature	•	1
	Material will not set due to not following design asphalt content and has to be redone	•	1
	4 – 8 hours for proper cure	•	1
	Delayed Set Time	•	1
	Oil tests	•	1
	Immediate raveling	•	1
Q5	**Have you experienced any performance problems with slurry and micro-surfacing systems <u>after</u> construction?**		
A1	**Frequency: Slurry Seals**	•	1
Most Often:	Loss of aggregate, flushing, pop offs because cracks not sealed properly	•	1
Least Often:			0
A2	**Frequency: Micro-Surfacing**	•••••••••	9
Most Often:	Adhesion and scar marks from equipment and/or isolated traffic	•	1
	Potholing: 40%	•	1
	Over asphalted sections rut	•	1
	Reflective cracking coming through in short period of time	•	1
	Rutting (2 projects since 1989)	•	1
	Loss of aggregate, flushing, pop offs because cracks not sealed properly	•	1
	Roughness due to reflective cracks and raveling due to poor mix	•	1

	Snow plow blades strip material from the centerline and edge of shoulder	•	1
Least Often:	Wears off: 10%	•	1
	Delamination	•	1
	Poor bonding to underlying pavement resulting in surface shelling off, most likely from snow plow forces	•	1
	Raveling (1 project since 1989)	•	1
	Rutting	•	1
	Bubbling surface during hot weather after surface is cured	•	1
	Snow plow blades skip on the roadway scoring portions of the surface	•	1
Q6	**Do you perform any QA testing and evaluation of these systems? Please explain:**		
A1	**For Micro-Surfacing**	••••••••••	10
	QC is by contractor, however gradation, moisture and quantities are checked by KDOT	•	1
	Previously, acceptance based on tests from sublots. Now a warranted pavement specification	•	1
	Blended aggregates checked to insure compliance with job mix formula. 500 feet test strip placed to inspect final product. Prior to placement, contractors are pre-qualified.	•	1
	Gradation, Emulsion tests – Require contractor to perform mix design	•	1
	Emulsion samples every 50,000 gals	•	1
	Gradation, moisture, sand equivalent on aggregate	•	1
	Sample oil and aggregate and mix design	•	1
	QA limited to testing aggregate grading and binder characteristics for specification conformance	•	1
	Asphalt content plus a visual acceptance in field	•	1
	Samples of aggregate and emulsions taken before. Mix design evaluated. Contractors QC program evaluated. Thickness measured from cores	•	1
	Independent testing of oil and aggregates	•	1
A2	**For Slurry Seals**	•••	3
	QA limited to testing aggregate grading and binder characteristics for specification conformance	•	1
	Asphalt content plus a visual acceptance in field	•	1
	Independent testing of oil and aggregates	•	1
A3	**No QA Testing**	•••••••	7
	Test the mix design when required by the state	•	1
	There is an on going 5 year evaluation of the two state highway projects	•	1
Q7	**Other Comments:**	•••••••••	9
	KDOT has used slurry seals from early 1970s with good performance; micro-surfacing has been used exclusively for last 15 years	•	1
	The reason for a warranted specification for micro-surface is the difficulty in getting an accurate representative sample of the mixture from the pavement	•	1
	A problem is that they do not set as quickly as advertised. Illinois has very limited experience on state routes, local roads have more experience. Want to gain knowledge from this pooled fund study to evaluate and implement micro-surfacing	•	1
	Would like to see improvement in the ISSA mix design procedures, specifically incorporate a procedure that optimizes the emulsion content and also provide a test procedure to evaluate rut resistance of the mixture	•	1
	WYDOT includes a non-polishing specification for the aggregate used in areas with extremely high truck traffic and where polishing of aggregate has occurred. Have not experienced significant rutting when this specification has been required	•	1
	Slurry seals were previously used on community airports but not in recent years	•	1
	Micro-surfacing used on only 3 projects to date	•	1
	Looking forward to seeing standardized mix design procedures	•	1
	Micro-surfacing performed well as cost effective alternative to thin overlays. Very good frictional resistance numbers. Does not prevent reflective cracking or improve rutting very well. Snow removal more difficult on micro-surfacing. On interstate, plow blades would skip or bounce on the roadway gouging micro- surface	•	1

	Product performance depends on experience of contractor, pavement/surface treated and traffic load	•	1
	Having problems with ride quality, rough surface and not a smooth and level centerline joint	•	1

CALTRANS PROJECT 65A0151
SLURRY AND MICRO-SURFACING MIX DESIGN PROCEDURES

RESPONSES TO QUESTIONS FOR ADVISORY PANEL CONTRACTORS

Q1	**Please indicate who designs your slurry seals and micro-surfacing mixtures:**		
A1	**Private testing laboratory**	•	1
A2	**Emulsion Supplier**	•••	3
A3	**Other:**	••	2
	All work was in house, i.e. emulsion manufacture, slurry design and application all by the same company	•	1
	Produce asphalt emulsifiers and additives. Do evaluate asphalt and aggregate compatibility for slurry seal and micro-surfacing to give customers mix optimizations	•	1
Q2	**What are the biggest areas of complaint from your customers?**		
A1	**Service Life**	•	1
A2	**Traffic Time**		0
A3	**Adaptability to conditions**	•	1
A4	**Other:**	••	2
	Occasional softness of mix on curing (noticeable under moderately high pavement temperatures). At times mix can remain lively many months after completion.	•	1
	Usually has to do with aesthetics such as color, texture or workmanship	•	1
Q3	**Do the slurry seal and micro-surfacing mix design provided to you satisfy your requirements in terms of being able to mix, place and finish the system? Please indicate below (Yes/No):**		
A1	**Slurry Seals**	••	2
Mix	Yes	••	2
	No		0
Place	Yes	••	2
	No		0
Finish	Yes	••	2
	No		0
A2	**Micro-Surfacing**	••	2
Mix	Yes	••	2
	No		0
Place	Yes	••	2
	No		0
Finish	Yes	••	2
	No		0
Q4	**Do you make adjustments to the mix design in the field? Please indicate the reasons below:**		
A1	**Adjustments to Slurry Seals:**	••	2
Reason	For cure time	•	1
	Occasionally will increase or lower the emulsion content by half percent. Always make small adjustments to the water and filler content but usually within parameters of the design	•	1
A2	**Adjustments to Micro-Surfacing:**	•••	3
Reason	For work or mix time	•	1
	Water and cement adjusted depending on weather and aggregate reactivity	•	1
	Most adjustments relate to water, additive and mineral filler but are usually within parameters set forth by the design	•	1
Q5	**Have you encountered problems reproducing the laboratory mix design in the field?**		

A1	**Yes, with slurry seal:**		0
A2	**Yes, with micro-surfacing**	•••	3
	Mineral filler required is sometimes as low as 0.5%, some machines have a hard time providing consistent flow at this low amount	•	1
	Mainly due to variability in stockpile moisture and level of fines in aggregate	•	1
	One major problem with a night time micro-surfacing project that was exposed to heavy traffic and rain very soon after application. The design did not identify the sensitivity to moisture during the transition of going from early rolling traffic cohesion to final cure and set	•	1
A3	**No**	•	1
Q6	**Other Comments:**	••••	4
	Biggest problem is selecting AE content for the design as typical window is too wide, sometimes as wide as 6% but usually 2 – 4 %	•	1
	Above comments are based on past experience since PRS is not currently an active contractor in this field	•	1
	In contact with emulsion producers and contractors as issues arise with field application. The primary cause of application problems in the field comes from variability (ratio and quantity) of mix components in the field. When the mix optimizations recommended are followed in the field, see good performance in the field. Most problems arise from changes in asphalt or aggregate sources. Other problems come from changes in the ratio of components in the mix or significant changes in the environmental conditions.	•	1
	Did not answer Q3 because in general do not have problems with mixing, placing or finishing but do not think mix designs are the primary reason for that. Most success with mixing, placing and finishing comes from the experience of our people and past experience with the materials. Do not use the design process to identify possible issues may face with the materials but do not believe it is driving force regarding success of mixing, placing and finishing. Very adamant with suppliers the best possible raw materials available are expected.	•	1

CALTRANS PROJECT 65A0151
SLURRY AND MICRO-SURFACING MIX DESIGN PROCEDURES

RESPONSES TO QUESTIONS FOR INDUSTRY PARTICIPANTS

Q1	**Do you design slurry seals and/or micro-surfacing systems?**		
A1	**Yes**	••••••••••••••••••	18
Design Methods Used	ISSA	•••••••••••••	13
	Modifications	•	1
	Colfalt plus	•	1
	Rut filling	•	1
	Include 6 Day WTAT's	•	1
	Varies based on pavement needs	•	1
	Based on project's agency	•	1
	Modified by project's agency	••	2
	ASTM D 3910	•	1
	DH-S 415/2546 (Dept. of Highway Specifications, Thailand)	•	1
	MDOT, SHA Standard Specs for Construction and Materials, Section 923, Maryland	•	1
	MSMT 403 (Maryland Std Method)	•	1
	International Slurry Seal Association TB 139	•	1
	Illinois DOT specifications and special provisions	•	1
A2	**Plan To**	•••	3
Design Methods Used	ISSA	•	1
	New Method and Modifications	•	1
	No Change	•	1
A3	**No**	••••••	6
Particular Reason	Not Equipped	•	1
	No lab, rely on suppliers and experience	•	1
	Akzo Nobel and Westvaco did the design	•	1
	Designs completed by contractor	•	1
	Provide input to suppliers who do design	•	1
Q2	**In what way is the design method you use or plan to use different from the ISSA Procedure?**		
A1	**No Difference**	•••••••••	9
A2	**Minor Difference**	•••••••••	9
Explain	Add cured cohesion to tune Portland Cement content	•	1
	Add any tests required by agency	•	1
	6 day WTAT	•	1
	Early cohesion of mix assessed subjectively	•	1
	Differences in applications rates and rock gradations	•	1
	Internal methods based on varying environmental traffic conditions	•	1
	As required by specifying agency	•	1
	DH-S 415 requires Hubbard Field Stability at 25 C not less than 1200 kg	•	1
	Does not use cohesive or loaded wheel test	•	1
	Seldom use TB 109 or TB 147	•	1
	For TB 100 do not use 6 day soak	•	1
	For TB 144 usually use abrasion results as design tool	•	1
	Refer to MSMT 403	•	1
A3	**Major Difference**	•	1
Explain	Use of range of conditioning methods	•	1
A4	**Don't Know**	•••	3
	Not familiar with ISSA design procedure	•	1
	Have to check with Ergon/Koch and Akzo	•	1

Q3	**In the design method you use or plan to use, are there any test methods and/or procedures that need to be revised or eliminated?**		
A1	**No**	••••••••••••	12
A2	**Yes**	•••••••••	9
List Methods and Explain	Use experience with common materials as much as lab mix designs	•	1
	All need to be looked at and appropriateness determined for each test	•	1
	Optimum water content by slump test bears little resemblance to amount used in field and of little use	•	1
	Wet stripping test passed too easily by most mixes and not good surrogate for Wet Track Abrasion Test	•	1
	Tightening up of test conditions for Cohesion test	•	1
	Major challenge of ISSA is preparation of precision statements for all tests	•	1
	WTAT good tool for determining base line AC content but screens off larger stones. Should be redesigned as a two part test.	•	1
	Wet Track Abrasion Test (TB 100) is good test for determining minimum emulsion content but operator sensitive. Six day soak version correlates closely to Schulze-Breuer method	•	1
	Need more time to answer question since some procedures are too subjective	•	1
	Hubbard Field Stability Test is obsolete	•	1
	Loaded wheel test with hot sand. Test not reliable or repeatable	•	1
	In agreement with Roger Smith's work regarding limitations of our test procedures	•	1
A3*	**Not Sure**	•	1
Added by Participant	Not sure current mix design standards accurately predict performance	•	1
Q4	**In the design method you use or plan to use, which mix design procedure/criteria relates to construction and/or long-term performance? Please explain why you think there is a relationship to construction and/or long-term performance.**		
A1	**Construction**	•••••••••••••••	15
List Criteria and Explain	ISSA mix test TB 113, TB 100, TB 139 especially using different cure times and conditioning	•••	3
	Lab work has difficulties judging mix time, set time and estimating break control additive usage	•	1
	Cohesion test and consistency test helps proper proportioning of materials	•••	3
	Mixing time test critical to workability	•••	3
	All of above relates to construction but construction results provide for long term performance	•	1
	Set Time. Minimum time to cure before opening to traffic	•••	3
	Optimum Mix water	•	1
	Mix tests give general indication if materials will work	•	1
	Flow	•	1
	Mixing and Curing tests	•	1
	Looking for a smoother ride quality	•	1
A2	**Long Term Performance**	•••••••••••••••	15
List Criteria and Explain	Shultz Bruer and Ruck	•••	3
	LWT deformation TB 147, TB 109, aggregate tests, binder tests (RBSP/PEN), TB 100 6 day soak	•	1
	6 day soak WTAT over all other lab test to estimate performance	•	1
	The WTAT allows enough asphalt to be incorporated into the mix to prevent aggregate loss	•	1
	Wet Track Abrasion Test (6 day soak) gives reasonable feel for mix integrity and durability	••	2

	Current emulsion type and residual asphalt percent provides an indication of durability and/or adhesiveness	•	1
	WTAT, LWT	••••	4
	Optimum emulsion content	•	1
	In the case of micro, important to fulfill the mix design to have good performance	•	1
	TB 114, TB 100, TB 109	•	1
	If slurry not constructed properly, it may be susceptible to damage early in life. For example, very slow set systems may be damaged by frost overnight and very fast break systems may break before adequately laid leading to stripping and delamination.	•	1
	Number of passes and condition of existing pavement	•	1
	The LWT does not do an adequate job for latex or polymer modified systems in giving the maximum emulsion content allowed by design	•	1
	Wet Track Abrasion Loss and Hubbard Field Stability	•	1
Q5	**What types of complaints do you receive from your customers:**		
A1	**Most Often**	•••••••••••••••••••	19
	Rough surface, worst paving ever, chatter	••	2
	Hot weather tenderness of mat (power steering marks)	••	2
	Traffic times and early damage	•	1
	Ugly handwork	••	2
	Workmanship issues	•	1
	Emulsion is breaking to fast	•	1
	Equipment related (maintenance)	•	1
	Application rate designated by engineers can lead to very coarse rock placed at too light an application rate	•	1
	Perception of rough ride	•	1
	Why does it take so long?	•	1
	6 Day soak for WTAB test	•	1
	Product sets up too quickly	•	1
	Potholes form in the micro, underlying asphalt pavement layer exhibits stripping	•	1
	Lose painted centre line	•	1
	Complexity of design and associated time and costs	•	1
	Classification compatibility – true meaning of grading scale	•	1
	Power steering abrasion	•	1
	Loose stone in the first few weeks	•	1
	Color, cracking, texture	•	1
	Economics	•	1
	Emulsion floats on surface and aggregate sinks down	•	1
	Aggregate variability	•	1
A2	**Least Often**	••••••••••••	12
	Long term performance	•	1
	Reflective cracking and ride improvement	•	1
	Too little asphalt/emulsion in mix	•	1
	Occasional slow cure	•	1
	Seldom get complaints about color, surface texture or long term serviceability	•	1
	Loose surface aggregate	•	1
	AE quality	•	1
	Cohesion	••	2
	Competent work force	•	1
	Proper equipment	•	1
	Construction management	•	1
	Instant breaking, slow curing and lose of aggregate	•	1
	Tenderness issues in quick release to traffic	•	1
	Centerline seam too high	•	1
A3	**No complaints**		0

Q6	**What do you try most to control or allow for in field operations and Why?**	••••••••••••••••••••••	22
	Use of water	•••	3
	Too much water causes bleeding, flushing, wet spots, raveling and floating of emulsion. Too little causes raveling, delamination, dry mat, pulling on material	•	1
	Mix Time	••	2
	Set times	••	2
	Aggregate and emulsion application rates	•	1
	Good workmanship and inventory control to track mix proportions	•	1
	Optimum emulsion/ emulsifier formulations for particular projects	•	1
	Allow for moisture and cement levels that dictate workability given usual weather and aggregate variations	•	1
	Variations in materials, aggregate changes, emulsion base stock changes, emulsion temperature variations and contamination of emulsion/rock	••	2
	To keep traffic off surface until thoroughly cured	•	1
	Uniformity	•	1
	Allow minor changes in water and additive	•	1
	Good transverse joints	•	1
	Mix design is only a guideline, field adjustments are required	•	1
	Quality of all materials including latex, machine calibration and machine settings	•	1
	Appropriate proportioning of emulsion and aggregate	•	1
	Ride quality	•	1
	Surface condition and vehicular and pedestrian traffic	•	1
	Allow for additive control of mix and control of emulsion and aggregate supply	•	1
	Ease of contractor use of the materials in construction while providing best performing system as possible	•	1
Q7	**Other Comments:**	••••••••••	10
	Emulsion supplier does design work, not very familiar with design changes	•	1
	Most problems due to aggregate suppliers	•	1
	Wet aggregate stockpiles	•	1
	Difficult for lab design to adjust for field conditions	•	1
	Gradation tolerances are too tight.	•	1
	Test methods need to be reviewed, updated and standardized	•	1
	Developed test methods will be too complicated and expensive for market	•	1
	In our area there is a poor understanding of slurry systems	•	1
	Repeatability of our tests is major issue	•	1
	Mix consistency	•	1
	ISSA should take serious response to member request for technical advise	•	1
	Still in trial period and will take few years to receive quality product expected. Will keep writing our specifications to fit our needs	•	1
	Skid resistance technical advise required	•	1

APPENDIX C REVIEW AND ABSTRACT ANALYSIS OF RESPONSES

CALTRANS PROJECT 65A0151
SLURRY AND MICRO-SURFACING MIX DESIGN PROCEDURES

RESPONSES TO QUESTIONS FOR AASHTO LISTSERVE RECIPIENTS

Q1	**Do you currently use or plan to use slurry seals and/or micro-surfacing systems on your roadway system?**		
A1	**Yes (71%)**	●●●●●●●●●●●●●●●	15
Quantities Used in Yd^2	Slurry Seal in 2001: no records		0
	Slurry Seal in 2002: Values: 6,980,000; 10,000	●●	2
	Slurry Seal in 2003: Values: 6,220,000; 35,066	●●	2
	Micro-surfacing in 2001: Average 944k, Stdev. 772k Values: 773,642; 2,200,000; 704,000; 1,907,289; 153,100; 75,000; 285,814; 1,536,000; 862,720	●●●●●●●●●	9
	Micro-surfacing in 2002: Average 663k, Stdev. 513k Values: 997,673; 1,000,000; 203,980; 704,000; 1,779656; 760,000; 146,000; 96,000; 56,000; 382,480	●●●●●●●●●●	10
	Micro-surfacing in 2003: Average 717k, Stdev. 620k Values: 497,700; 70,400; 1,000,000; 46,424; 704,000; 1,816,029; 1,430,000; 82,000; 417,905; 1,449,000; 384,500	●●●●●●●●●●●	11
A2	**Plan To (76%)** Note that of the 16 affirmative answers, 4 mentioned that only micro-surfacing will be used in the future	●●●●●●●●●●●●●●●●	16
A3	**No (29%)**	●●●●●●	6
Particular Reason	Existing micro-surfacing is exhibiting severe potholes and deterioration of underlying AC results	●	1
	No success with slurry seals when tried a couple of years ago	●	1
	Prefer 1 inch HMAC overlays for thin surface treatments	●	1
	Slurry seals have not performed to expectations and micro-surfacing is not cost effective	●	1
	Previous research by NJDOT recommended that slurry seals not be used on roads with AADT>10,000. All NJDOT roads have AADT>10,000.	●	1
	Slurry seals used by maintenance for transverse crack sealing but not as a surface treatment due to slow cure	●	1
Q2	**If you currently use these systems, do you expect to continue to use them? Please explain why:**		
A1	**Yes (100%)**	●●●●●●●●●●●●●●●	15
Explain	Temporary rehab method and/or for purpose of temporarily increasing pavement friction	●	1
	Micro-surfacing good treatment for skid resistance, filling in ruts and pavement preservation	●	1
	Based on the good performance over several years	●	1
	Micro-surface can be used as a surface maintenance treatment	●	1
	Provides a relatively inexpensive new surface that renews friction and preserves underlying pavement from further environmental deterioration	●	1
	Good maintenance strategy for extending pavement life for roadways that do not require structural overlay but are exhibiting rutting or loss of friction	●	1
	The use of micro-surfacing will continue to grow and is usually used on higher volume roads > 10,000 AADT	●	1
	Excellent performance with micro-surfacing put down 5 years ago. Expecting 8 to 10 years of service life with wear and sealing factors. If road testing shows base to be in good condition, another micro on same high volume roadways is feasible	●	1
	Use expected to continue on appropriate projects	●	1
	Slurry seals and micro-surfacing are performing satisfactorily	●	1
	Micro-surfacing improves skid, thin lift seals cracks, extends pavement life	●	1
	Micro-surfacing will be used as a cost effective approach to the state's pavement preventative maintenance program	●	1
	Excellent results when used as a seal cost versus oil and chip at a similar price	●	1
	Found it to be a good alternative to seal coat for high traffic roads, subdivisions, villages and low traffic county highways	●	1

A2	**No (0%)**		0
Q3	**What is your experience/expectations regarding the service life of slurry seals and micro-surfacing systems (how long do you expect them to last)? Include traffic volume, intersection versus mainline and other details, if needed:**		
A1	**Service Life: Slurry Seals (average 3 – 5 years)**	•••	3
From Past Experience:	3 – 5 years	••	2
Expected:	2 years	•	1
	3 – 5 years	••	2
	5 years	•	1
A2	**Service Life: Micro-Surfacing (average 5 – 7 years)**	•••••••••••••	13
From Past Experience:	3 – 5 years	•••••	5
	5 – 7 years	•••	3
	4 – 12 years	•	1
	5 – 15 years	•	1
	8 – 10 years	•	1
	1 – 4 years	•	1
Expected:	3 – 5 years	••••	4
	5 – 7 years	•••••••••	9
	8 – 10 years	•••	3
A3	**Other Comments**		
	Not recommended on Interstates, Freeways and Expressways		
	Micro material which lasted 2 years had AADT of 11,000		
	Durability dependent upon existing roadway and placement conditions and surface loading. Missouri experience is towards placing the surface on poorer existing surfaces instead of as a preventive maintenance treatment		
	Experience extremely limited		
	Past experience life is based on data from 1990 to present and from micro-surfacing until another action. Micro-surfacing condition may not have been reason for action. Service life up to 6 years at 7000 AADT on some sections. Majority of sections with AADT<3000 have 3 – 6 years service life		
	Slurry seals utilized on secondary roads and some micro-surfacing done on lower volume primary roads		
	Expected 4 to 5 years with good mix and quality placement		
	Three projects micro-surfaced in 2001: 2 state highways and 1 interstate highway		
	New to our department, trying it out, looking for alternatives to seal coats		
Q4	**Have you experienced any performance problems with slurry and micro-surfacing systems <u>during</u> construction?**		
A1	**Frequency: Slurry Seals**	•••	3
Most Often:	Hard to control	•	1
	Mix issues – correct proportions of aggregate and asphalt	•	1
	Insuring lime feed is working	•	1
Least Often:			0
A2	**Frequency: Micro-Surfacing**	••••••••••••	12
Most Often:	Traffic control	•	1
	Cure time related	•••	3
	Workmanship	•••	3
	Emulsion quality control	•	1
	Control of water added	••	2
	Set time related	•	1
	Raveling	•	1
	Contractor testing of aggregate	•	1
	Mix issues – correct proportions of aggregate and asphalt	•	1
	Insuring lime feed is working	•	1
	Roughness due to screed problems and due to reflective cracks	•	1
	Loss of stone matrix in wheel path shortly after roadway opened to traffic	•	1

Least Often:	Joints	•	1
	Temperature	•	1
	Set time related	••	2
	Cure time related	•	1
	Oil tests	•	1
	Immediate raveling	•	1
Q5	**Have you experienced any performance problems with slurry and micro-surfacing systems after construction?**		
A1	**Frequency: Slurry Seals**	•	1
Most Often:	Loss of aggregate, flushing, pop offs because cracks not sealed properly	•	1
Least Often:			0
A2	**Frequency: Micro-Surfacing**	•••••••••	9
Most Often:	Adhesion and scar marks from equipment and/or isolated traffic	•	1
	Potholing	•	1
	Rutting	••	2
	Reflective cracking coming through in short period of time	••	2
	Loss of aggregate, flushing, pop offs because cracks not sealed properly	•	1
	Raveling	•	1
	Snow plow blades strip material from the centerline and edge of shoulder	•	1
Least Often:	Wears off	•	1
	Delamination	••	2
	Raveling	•	1
	Rutting	•	1
	Bubbling surface during hot weather after surface is cured	•	1
	Snow plow blades skip on the roadway scoring portions of the surface	•	1
Q6	**Do you perform any QA testing and evaluation of these systems? Please explain:**		
A1	**For Micro-Surfacing**	••••••••••	10
	QC is by contractor, however gradation, moisture and quantities are checked by KDOT	•	1
	Previously, acceptance based on tests from sublots. Now a warranted pavement specification	•	1
	Blended aggregates checked to insure compliance with job mix formula. 500 feet test strip placed to inspect final product. Prior to placement, contractors are pre-qualified.	•	1
	Gradation, Emulsion tests – Require contractor to perform mix design	•	1
	Emulsion samples every 50,000 gals	•	1
	Gradation, moisture, sand equivalent on aggregate	•	1
	Sample oil and aggregate and mix design	•	1
	QA limited to testing aggregate grading and binder characteristics for specification conformance	•	1
	Asphalt content plus a visual acceptance in field	•	1
	Samples of aggregate and emulsions taken before. Mix design evaluated. Contractors QC program evaluated. Thickness measured from cores	•	1
	Independent testing of oil and aggregates	•	1
A2	**For Slurry Seals**	•••	3
	QA limited to testing aggregate grading and binder characteristics for specification conformance	•	1
	Asphalt content plus a visual acceptance in field	•	1
	Independent testing of oil and aggregates	•	1
A3	**No QA Testing**	•••••••	7
	Test the mix design when required by the state	•	1
	There is an on going 5 year evaluation of the two state highway projects	•	1
Q7	**Other Comments:**	•••••••••	9
	KDOT has used slurry seals from early 1970s with good performance; micro-surfacing has been used exclusively for last 15 years	•	1
	The reason for a warranted specification for micro-surface is the difficulty in getting an accurate representative sample of the mixture from the pavement	•	1

	A problem is that they do not set as quickly as advertised. Illinois has very limited experience on state routes, local roads have more experience. Want to gain knowledge from this pooled fund study to evaluate and implement micro-surfacing	•	1
	Would like to see improvement in the ISSA mix design procedures, specifically incorporate a procedure that optimizes the emulsion content and also provide a test procedure to evaluate rut resistance of the mixture	•	1
	WYDOT includes a non-polishing specification for the aggregate used in areas with extremely high truck traffic and where polishing of aggregate has occurred. Have not experienced significant rutting when this specification has been required	•	1
	Slurry seals were previously used on community airports but not in recent years	•	1
	Micro-surfacing used on only 3 projects to date	•	1
	Looking forward to seeing standardized mix design procedures	•	1
	Micro-surfacing performed well as cost effective alternative to thin overlays. Very good frictional resistance numbers. Does not prevent reflective cracking or improve rutting very well. Snow removal more difficult on micro-surfacing. On interstate, plow blades would skip or bounce on the roadway gouging micro-surface	•	1
	Product performance depends on experience of contractor, pavement/surface treated and traffic load	•	1
	Having problems with ride quality, rough surface and not a smooth and level centerline joint	•	1

CALTRANS PROJECT 65A0151
SLURRY AND MICRO-SURFACING MIX DESIGN PROCEDURES

REVIEWED RESPONSES TO QUESTIONS FOR ADVISORY PANEL CONTRACTORS

Q1	**Please indicate who designs your slurry seals and micro-surfacing mixtures:**		
A1	**Private testing laboratory**	•	1
A2	**Emulsion Supplier**	••••	3
A3	**Other:**		0
Q2	**What are the biggest areas of complaint from your customers?**		
A1	**Service Life**	•	1
A2	**Traffic Time**		0
A3	**Adaptability to conditions**	•	1
A4	**Other:**	••	2
	Aesthetics	•	1
	Slow curing especially in hot weather conditions	•	1
	Workmanship	•	1
Q3	**Do the slurry seal and micro-surfacing mix design provided to you satisfy your requirements in terms of being able to mix, place and finish the system? Please indicate below (Yes/No):**		
A1	**Slurry Seals**	••	2
Mix	**Yes**	••	2
	No		0
Place	**Yes**	••	2
	No		0
Finish	**Yes**	••	2
	No		0
A2	**Micro-Surfacing**	••	2
Mix	**Yes**	••	2
	No		0
Place	**Yes**	••	2
	No		0
Finish	**Yes**	••	2
	No		0
Q4	**Do you make adjustments to the mix design in the field? Please indicate the reasons below:**		
A1	**Adjustments to Slurry Seals:**	••	2
Reason	Adjust emulsion content within +/- 0.5 % to mitigate extreme tackiness	•	1
	Minor adjustments to water and filler content – within the design parameters	•	1
	To control cure time	•	1
A2	**Adjustments to Micro-Surfacing:**	•••	3
Reason	Minor adjustments to water, filler and emulsion content – within the design parameters	•	1
	Minor adjustments to water and filler content – depending on weather and aggregate reactivity	•	1
	To control workability/mix time	•	1
Q5	**Have you encountered problems reproducing the laboratory mix design in the field?**		
A1	**Yes, with Slurry Seal:**		0
A2	**Yes, with Micro-Surfacing**	•••	3
	Mineral filler required is sometimes as low as 0.5%, some machines have a hard time providing consistent flow at this low amount	•	1

	Mainly due to variability in stockpile moisture and level of fines in aggregate	•	1
	One major problem with a night time micro-surfacing project that was exposed to heavy traffic and rain very soon after application. The design did not identify the sensitivity to moisture during the transition of going from early rolling traffic cohesion to final cure and set	•	1
A3	**No**	•	1
Q6	**Other Comments:**	••••	4
	Biggest problem is selecting emulsion content for the design as typical window is too wide, sometimes as wide as 6% but usually 2 – 4 %	•	1
	Above comments are based on past experience since PRS is not currently an active contractor in this field	•	1
	In contact with emulsion producers and contractors as issues arise with field application. The primary cause of application problems in the field comes from variability (ratio and quantity) of mix components in the field. When the mix optimizations recommended are followed in the field, see good performance in the field. Most problems arise from changes in asphalt or aggregate sources. Other problems come from changes in the ratio of components in the mix or significant changes in the environmental conditions.	•	1
	Did not answer Q3 because in general do not have problems with mixing, placing or finishing but do not think mix designs are the primary reason for that. Most success with mixing, placing and finishing comes from the experience of our people and past experience with the materials. Do not use the design process to identify possible issues may face with the materials but do not believe it is driving force regarding success of mixing, placing and finishing. Very adamant with suppliers the best possible raw materials available are expected.	•	1

CALTRANS PROJECT 65A0151
SLURRY AND MICRO-SURFACING MIX DESIGN PROCEDURES

REVIEWED RESPONSES TO QUESTIONS FOR INDUSTRY PARTICIPANTS

Q1	**Do you design slurry seals and/or micro-surfacing systems?**		
A1	**Yes**	••••••••••••••••	16
Design Methods Used	ISSA	•••••••	7
	ISSA with Modifications	•••••	5
	ASTM	•	1
	DOT Specification	•••	3
A2	**Plan To**	•••	3
Design Methods Used	ISSA	••	2
	New Method with Modifications	•	1
A3	**No**	•••••	5
Particular Reason	Not equipped (with a laboratory)	••	2
	Designs completed by contractor or emulsion supplier	•••	3
Q2	**In what way is the design method you use or plan to use different from the ISSA Procedure?**		
A1	**No Difference**	•••••••	7
A2	**Minor Difference**	••••••	6
Explain	Add cured cohesion test to determine portland Cement content	•	1
	Modify according to agency requirements	••	2
	Include 6 day WTAT test	•	1
	Early cohesion of mix assessed subjectively by kneading of sample after break	•	1
	Differences in applications rates and rock gradations	•	1
	Internal methods based on varying environmental traffic conditions	•	1
	As required by specifying agency	•	1
	According to Thailand Department of Highways Specification DH-S 415: requires Hubbard Field Stability at 25 C not less than 1200 kg	•	1
	Do not use cohesive or loaded wheel test	•	1
	Seldom use ISSA Technical Bulletin 109 or 147	•	1
	For ISSA Technical Bulletin 100, do not use 6 day soak	•	1
	For ISSA Technical Bulletin 144, only use abrasion results as design tool	•	1
	According to Maryland Standard Method of Test MSMT 403	•	1
A3	**Major Difference**	•	1
Explain	Use of range of conditioning methods	•	1
A4	**Don't Know**	••	2
	Not familiar with ISSA design procedure	•	1
	Have to check with Ergon/Koch and Akzo	•	1
Q3	**In the design method you use or plan to use, are there any test methods and/or procedures that need to be revised or eliminated?**		
A1	**No**	••••••••••••	12
A2	**Yes**	•••••••••	9
List and Explain	Optimum water content by slump test bears little resemblance to amount used in field and of little use	•	1
	Wet stripping test passed too easily by most mixes and not good surrogate for Wet Track Abrasion Test	•	1
	Tightening up of test conditions for Cohesion test	•	1
	Major challenge of ISSA is preparation of precision statements for all tests	•	1

	WTAT good tool for determining base line AC content but screens off larger stones. Should be redesigned as a two-part test.	•	1
	Wet Track Abrasion Test (TB 100) is good test for determining minimum emulsion content but operator sensitive. Six day soak version correlates closely to Schulze-Breuer method	•	1
	Hubbard Field Stability Test is obsolete	•	1
	Loaded wheel test with hot sand. Test not reliable or repeatable	•	1
Q4	**In the design method you use or plan to use, which mix design procedure/criteria relates to construction and/or long-term performance? Please explain why you think there is a relationship to construction and/or long-term performance.**		
A1	**Construction**		
List Criteria and Explain	Trial Mix Procedure (ISSA TB 113)	••••••	
	WTAT (ISSA TB 100)	•	
	Modified Cohesion Test (ISSA TB 139)	•••••••••	
	Consistency Test (ISSA TB 106)	•	
	Optimum water content	•	
A2	**Long Term Performance**		
List Criteria and Explain	Schulze-Breuer and Ruck Procedure (ISSA TB 144)	•••	
	LWT Deformation (ISSA TB 147)	•	
	LWT (ISSA TB 109)	•••••	
	Aggregate Tests	•	
	Binder Tests	•	
	WTAT 6 days soak (ISSA TB 100)	•••	
	WTAT (ISSA TB 100)	•••••••	
	Wet Stripping Test (ISSA TB 114)	•	
	Optimum emulsion content	•	
Q5	**What types of complaints do you receive from your customers:**		
A1	**Most Often**		
Explain	Rough surface/ride	••	
	Hot weather tenderness of mat	••	
	Traffic time	•	
	Early traffic damage	•	
	Workmanship	••••	
	Break time related	•	
	Inappropriate application rate	•	
	Initial appearance	••••	
	Power steering abrasion	•	
	Aggregate variability due to lack of consistency in specification requirements	•	
	Complexity of design – time and cost associated	•••	
	Early distress (pot holes)	•	
	Set time related	•	
	Segregation	•	
	Loose aggregate	•	
A2	**Least Often**		
Explain	Long term performance	••	
	Reflective cracking	•	
	Not enough asphalt in the mix	•	
	Slow cure	•••	
	Appearance	•	
	Cohesion related	••	
	Emulsion quality	•	
	Loose aggregate	•	
	Brake time related	•	
	Workmanship	•	
A3	**No complaints**		

Q6	**What do you try most to control or allow for in field operations and Why?**		
Control	Water content	••••	4
	Mix time	••	2
	Set time	••	2
	Aggregate and emulsion application rates	•	1
	Good workmanship	••	2
	Mix proportions	••	2
	Emulsion content	•	1
	Keep traffic off surface until thoroughly cured	•	1
	Uniformity	•	1
	Quality of all materials including latex, machine calibration and machine settings	•	1
	Ride quality	•	1
	Surface condition and vehicular and pedestrian traffic	•	1
Allow	Allow for moisture and cement levels that dictate workability given usual weather and aggregate variations	•	1
	Variations in materials, aggregate changes, emulsion base stock changes, emulsion temperature variations and contamination of emulsion/rock	•••	3
	Allow minor changes in water and additive		1
	Allow for additive control of mix and control of emulsion and aggregate supply	•	1
Q7	**Other Comments:**		
	Emulsion supplier does design work, not very familiar with design changes	•	1
	Most problems due to aggregate suppliers	•	1
	Wet aggregate stockpiles	•	1
	Difficult for lab design to adjust for field conditions	•	1
	Gradation tolerances are too tight.	•	1
	Test methods need to be reviewed, updated and standardized	•	1
	Developed test methods will be too complicated and expensive for market	•	1
	In our area there is a poor understanding of slurry systems	•	1
	Repeatability of our tests is major issue	•	1
	Mix consistency	•	1
	ISSA should take serious response to member request for technical advise	•	1
	Still in trial period and will take few years to receive quality product expected. Will keep writing our specifications to fit our needs	•	1
	Skid resistance technical advise required	•	1

APPENDIX D MIXING BEHAVIOR OF ASPHALT EMULSIONS AND COMPATIBILITY OF MATERIALS (PTM 001)

DRAFT Proposed Method of Test for

Mixing Behavior of Asphalt Emulsions and Compatibility of Materials

AASHTO Designation: DRAFT Proposed Test Method 001 (PTM 001)

1. SCOPE

1.1. This method provides an objective evaluation of the breaking behavior of emulsions and compatibility of materials. By automatic and constant recording of the complete torque-measurement-curve, the mixing curve is indicating each variation during the breaking process. The evaluation takes place under tightly controlled conditions and the apparatus provides a report of results. The test measures the following:

- Mix consistency
- Mix stability or the changes of the mix consistency in relation to timing
- Breaking characteristics of the emulsion in the mix
- Temperature dependency of the mix

The main parameters determined from this test are a mix and spread index for design purposes. This is a matter of setting a maximum cohesion value (torque) where the liquid (slurry) state exists and a minimum time for this to remain so to allow adequate mixing of the components. The spread index is set at the maximum torque in the solid state where spreading may still occur and a minimum time where this will remain.

1.2. The proposed test method is applicable to slurry seal and micro-surfacing mixes.

1.3. The test method is in development.

1.4. The values stated in metric SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. ISSA TB 113, Trial Mix Procedure for Slurry Seal Design

2.2. Thin Lift in Cold-Applied Micro-Surfacing, Instructions for the Electric Mixing Test, (Translated from German)

2.3. Microvisc, Krause Technology GmbH

3. SUMMARY OF METHOD

3.1. The asphalt emulsion, aggregate, mineral filler, setting additives, and water are the components of the mix. The mix components, at the prescribed temperature, are weighed into separate containers. The other components will be added as described by the mix design or through pre-testing using the hand mixing method, ISSA TB 113. The asphalt emulsion and water (with additive) are put into the containers and placed into specific temperature-controlled water or air bath so that the Microvisc stirrer will be in the center of the mixing container. The rotation of the stirrer is started and maintained at 300 rpm. Immediately, the weighed aggregate and additive(s) are added while stirring (within 5 seconds). The mix is stirred constantly turning until it is thick. Production time and breaking time are noted as the consistency of the mix thickens. See Figure 1.

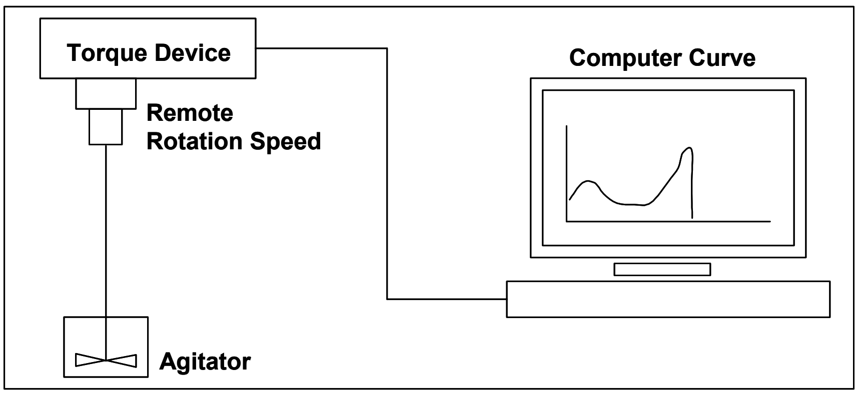

Figure 1. Summary of Test Method.

4. SIGNIFICANCE AND USE

4.1. This test method will measure compatibility and setting parameters of asphalt emulsions and mineral aggregates.

4.2. This procedure is suggested for establishing design criteria of the mix system. In addition, it provides a means of quality control during the production of asphalt emulsion, mineral aggregates, and additives.

4.3. This method facilitates research and development of new combinations of raw materials.

4.4. This method documents the temperature influences on the consistency of the mixed materials.

4.5. Description of the Curve, Figure 2. The shape of the curve is based on several mechanisms. The main features are liquid and the solid stages of the mix. The first is where the mix is fluid and may be easily mixed and moved by the machinery. The time over which this is possible is of interest as the mix time. The second is where the stiffer mixture is approaching a solid phase . The cohesion where the mix is so stiff it will not allow further mixing and the point where the spreadability is limited. That is, this can be used as a maximum cohesion for spreading or the spread time.

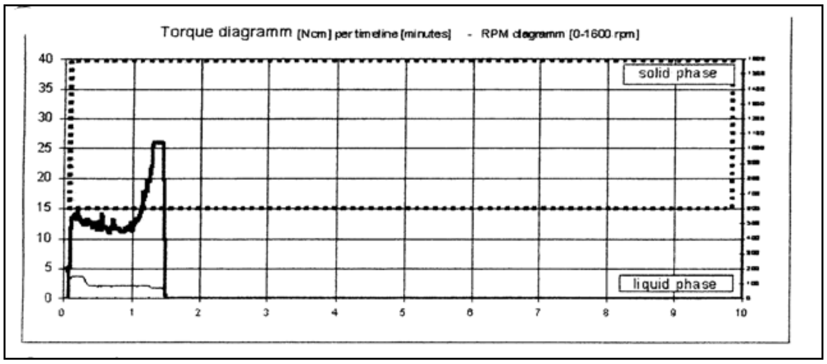

Figure 2. Description of the Curve

4.5.1. Mixing Time. This is the time that the mix is fluid, below the mix index cohesion. This is also the period over which the emulsion will still coat the aggregate.

4.5.2. Mix Index. This is the cohesion that is reached that still allows free mixing and is the flat part of the curve.

4.5.3. Spread Index. This is the cohesion where the mix stiffens to a point where it can just still be spread. The time to reach this point is an indication of break time .

4.5.4 Spread Time: This is the time that the mix takes to reach the limiting cohesion or spread index.

5. APPARATUS

5.1. Microvisc (or equivalent) agitator with electronic torque device and constant rotation speed, including "four-winged stirrer" or agitator head, able to maintain 300 rpm. See Figure 3.

5.2. Computer software for automatic measurement of torque, speed, and time at specific test temperatures

5.3. 500 ml Griffin plastic beaker, rounded bottom, 105 mm inside diameter

5.4. 500 ml Griffin heat resistant beaker, optional for testing at different temperatures

5.5. Stand to hold the beaker

5.6. Thermometer, 1°C increments, 1°C – 100°C range

5.7. Spatula, steel, with a stiff rounded blade, approximately 18mm (3/4 in.) in width and 100mm (4 in.) in length

5.8. Spray bottles, with distilled water and liquid setting additive

5.9. Scales, with capacity of 2000.0 g, accurate to +/- 0.1 g

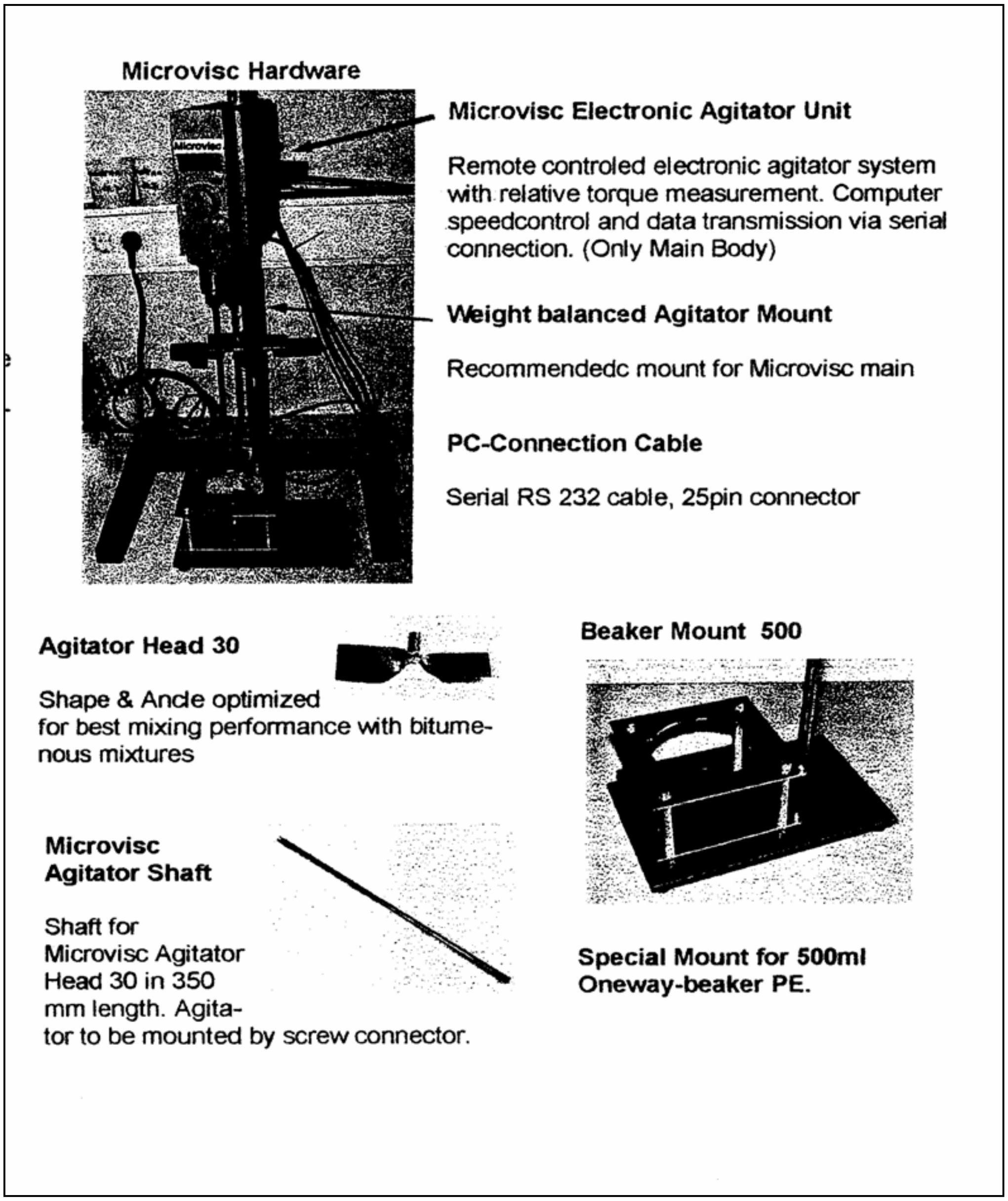

Figure 3. Apparatus.

6. MATERIALS

6.1. Aggregates--Sample representative portions of aggregates used for slurry seal mix or micro-surfacing mix. Use material of the type, grade, and source proposed for the project. Aggregates shall be dried at 60°C to a constant mass and cooled to the prescribed test temperatures prior to performing the test.

6.2. Asphalt Emulsion--Use material of the type, grade, and source proposed for the project. Asphalt emulsion shall be maintained at prescribed temperature for testing.

6.3. Setting Additives--Use liquid, powdered, or liquid (undiluted or diluted) setting additives where specified from the mix design or through pre-testing.

6.4 Mineral Filler

6.5 Water--Distilled water with a pH between 6.0 and 7.0 shall be used.

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7. PROCEDURE

7.1. Maintain the temperatures of the aggregate, emulsion, water, and additives to the prescribed testing temperature.

7.2. The amount of material components will be quantified as described by the mix design or through determinations from pre-testing using the hand mixing method. In order to minimize delays, all addition of materials, should be pre-determined and pre-weighed prior to starting the stirrer.

7.3. Add 600 g of aggregate into a second mixing container. If needed, add a prescribed amount of dry or powdered additive and mix well. It may be necessary to pre-wet the aggregate mixture with a small amount of water. Set aside to add into the emulsion and liquid additive container later.

7.4. Add the emulsion and liquid set additive to the mixing container. Set the stirrer in the center of the mixing container up to 1mm from the bottom/base and 16mm from the upper edge of the winged-stirrer. Then start the stirrer at 300 rpm. Stir for 5 seconds.

7.5. After the initial 5 seconds add the aggregate mixture to the emulsion.

7.6. The computer program will document the changes in the viscosity of the mixture as it thickens over time. It will measure changes from a fluid-like consistency to a solid broken mixture.

---

8. REPORT

8.1. Report the following information:

8.1.1. Aggregate: percent used, type of aggregate, source and the date received for testing.

8.1.2. Asphalt emulsion: percent used, type of emulsion, source and the date received for testing.

8.1.3. Mineral Filler: percent used and type.

8.1.4. Set additive(s): percent used, type, source, and the date received for testing.

8.1.5. Percent of water used to initially wet the aggregate, if needed.

8.2. From the curve of the mix, you get the following results:

8.2.1. Resting time: Consistency of the upper layer.

8.2.2. Mixing time: Time you have to place the layer, especially for good adhesion to the base.

8.2.3. Production time: Time in which you have to finish any corrections of the layer.

8.2.4. Breaking time: The point in time where the breaking begins to occur.

8.2.5. Total time for the mixture to completely break.

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9. PRECISION AND BIAS

9.1. This method is in development. At present, there is no precision and bias statement for this method.

APPENDIX E MEASUREMENT OF COHESION CHARACTERISTICS OF ASPHALT EMULSIONS AND AGGREGATE MIXTURE SYSTEMS (PTM 002)

DRAFT Proposed Method of Test for

Measurement of Cohesion Characteristics of Asphalt Emulsions and Aggregate Mixture Systems

AASHTO Designation: DRAFT Proposed Test Method 002 (PTM 002)

1. SCOPE

1.1. This test method describes the procedure for determining traffic time and 24-hour cure time for slurry seal and micro-surfacing mixes. The traffic time is a constructability parameter, which is a function of cohesion that the mix must reach in order to accept traffic without deformation to the applied material. This level of cohesion should be the same for any traffic type, but may require testing on different conditions depending on the application. The cohesion measurement will indicate the suitability of mixtures under a range of the following conditions: humidity, temperature, and daylight/darkness. The cohesion measurements will be performed on laboratory specimens with and without compaction, simulating early traffic and or rolling.

1.2. The proposed test method is applicable to slurry seal and micro-surfacing mixes.

1.3. The test method is in development.

1.4. The values stated in SI units are to be regarded as the standard.

---

2. REFERENCED DOCUMENTS

2.1. ASTM D 3910-98, Practice for Design, Testing, and Construction of Slurry Seal.

2.2. ASTM D 6372-99a, Practice for Design, Testing and Construction of Micro-Surfacing

2.3. ISSA TB 102, Mixing, Setting, and Water Resistance Test to Identify “Quick-Set” Emulsified Asphalt.

2.4. ISSA TB 139, Test Method to Classify Emulsified Asphalt/Aggregate Mixture Systems by Modified Cohesion Tester, Measurement of Set and Cure Characteristics

2.5. AASHTO PTM 001, Mixing Behavior of Asphalt Emulsions and Aggregate Mixtures and the Compatibility of Materials

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3. SUMMARY OF METHOD

3.1. Asphalt emulsion, aggregate, setting additives, mineral filler, and water are the components of the mix. The proportions of the components will be derived from the mix design and/or test results from AASHTO PTM 001. The mix components, at the prescribed temperature, humidity, compacted/uncompacted and day/night conditions, are cured for specific time periods. After curing, the specimen is centered under a lowered foot instrument and a 200 kPa clamping pressure is applied on the specimen. The foot is automatically twisted at a specific rate and time. A PC interface with an electronic strain gauge will be used to measure torque over time and to calculate the peak of cohesion. This is then related to the specified traffic time.

4. SIGNIFICANCE AND USE

4.1. This test method measures cohesion and setting parameters of asphalt emulsions and mineral aggregates. This method documents the influences of aging, humidity, temperature, and daylight/darkness on the curing of the mixed materials.

4.2. This procedure is suggested for establishing the mix design criteria. In addition, it provides a means of quality control during the production of asphalt emulsion, mineral aggregates, and additives.

4.3. The test method facilitates research and development of new combinations of raw materials.

5. APPARATUS

5.1. Modified cohesion tester, similar to the ASTM D3910-898 machine, but modified as follows:
5.1.1. 1-1/8” ϕ double rod end air cylinder with 5/16” ϕ rods and 3” stroke
5.1.2. ¼” x 1-1/8” ϕ 60 durometer neoprene rubber foot
5.1.3. Air pressure regulator with a variable down stream bleed valve so that constant pressure is maintained
5.1.4. Four-way directional control valve with exhaust port regulating valves.
5.1.5. Air pressure gauge with a 0 to 700 kPa (kilograms/sq.cm.) pressure gauge
5.1.6. 700 kPa (100 psi) air supply
5.1.7. Torque measurement device, measuring at least 35 kg-cm torque
5.1.8. Motorized cam providing shaft torque through 180° within 0.5 to 0.7 seconds

5.2. 15-pound saturated roofing felt or other suitable non-absorptive specimen mounting pads, 10 cm^2 in size

5.3. 6 mm x 60 mm diameter and 10 mm x 60 mm diameter specimen molds

5.4. 4.7 mm and 8.0 mm standard ASTM E 11 sieves
5.5. Scales, with capacity of 2000.0 g, accurate to +/- 0.1 g

5.6. Suitable mixing containers, spoons

5.7. Spatula, steel, with a stiff rounded blade, approximately 18mm (3/4 in.) in width and 100mm (4 in.) in length, for cleaning the foot surface

5.8. For calibration
5.8.1. 20-30 mesh standard ASTM C 190 Ottawa sand
5.8.2. 220 grit silicon carbide "3-M" brown sand paper
5.8.3. 100 grit silicon carbide "Carborundum" brand sand paper

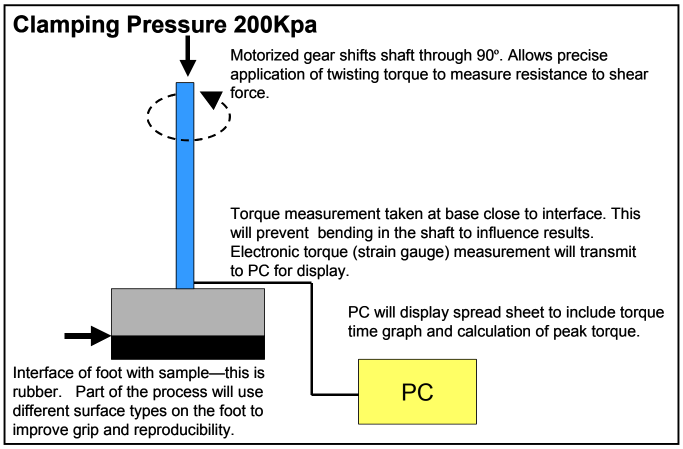

Figure 1. Apparatus.

5.9. Forced air draft ovens and environmental chambers, maintaining specific curing temperatures.

5.10. Humidity chamber for curing in high and low humidity conditions, see Figure 2.

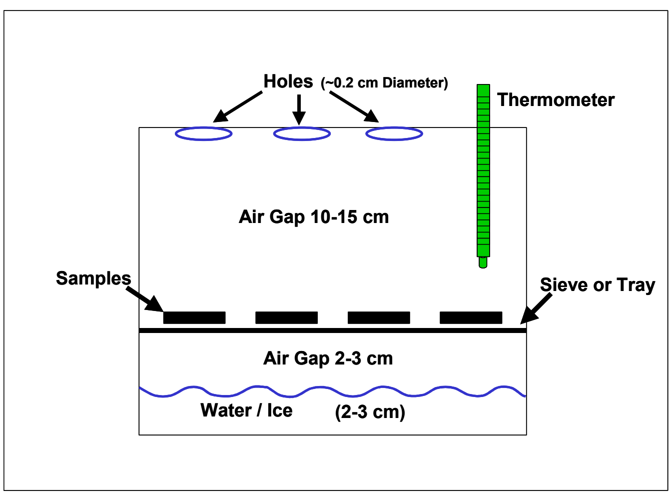

Figure 2. Apparatus 5.10.

5.11. Means of compacting specimens, if needed.

6. MATERIALS

6.1. Aggregates--Sample representative portions of aggregates used for slurry seal mix or micro-surfacing mix. Use material of the type, grade, and source proposed for the construction work. Aggregates shall be dried at 60°C to a constant mass and cooled to prescribed test temperatures prior to performing the test.

6.2. Asphalt Emulsion--Use material of the type, grade, and source proposed for the construction work. Asphalt emulsion shall be maintained at prescribed temperature for testing.

6.3. Setting Additives--Use liquid, powdered, or liquid (undiluted or diluted) setting additives where specified from the mix design or through pre-testing.

6.4. Water--Distilled drinking water with a pH between 6.0 and 7.0 shall be used.

7. PROCEDURE

7.1. Maintain test temperatures of the aggregate, emulsion, water, and additives at the prescribed testing temperature.

7.2. The amounts of material components will be quantified as described by the mix design or through determinations from pre-testing using the electric mixing method. In order to minimize delays, all additions of materials, should be pre-determined and pre-weighed prior to starting the stirrer.

7.3. Use the following curing conditions for applications under different environmental conditions:
7.3.1. Curing temperatures: 35°C, 25°C, or 10°C
7.3.2. Humidity ranges: <50%, 50-60%, or 90%
7.3.3. Curing ages: 1 hour, 24 hours

7.4. The specimen is centered under the neoprene foot, instrument air pressure set at 200 kPa, and the foot is lowered against the specimen at a rate of 8 to 10 cm per second. After 5 to 6 seconds of compaction, the torque meter is "zeroed" and twisted through a 180° arc within 0.5 to 0.7 seconds. The foot is raised and cleaned before the next specimen is tested.

8. CALIBRATION

8.1. A series of tests may be made with 220 grit sand paper until a series of 10 tests read a constant average, within a 0.3 kg-cm range.

8.2 After the rubber disc is "polished" with the 220 grit sand paper to a constant reading, the 20-30 mesh Ottawa sand contained in a 1 cm mold, and the 100 grit sand paper may be tested and the calibration reading recorded.

8.3. The dry aggregate used for the test mix should be tested as in 8.2 and recorded on the cohesion graph.

9. REPORT

9.1. Report the following information:

9.1.1. Aggregate: percent used, type of aggregate, source and the date received for testing.

9.1.2. Asphalt emulsion: percent used, type of emulsion, source and the date received for testing.

9.1.3. Set additive(s): percent used, type, source, and the date received for testing.

9.1.4. Percent of water used to initially wet the aggregate, if needed.

9.1.5. Curing conditions: temperature, humidity, day/night conditions, and time.

9.1.6. Cohesion test result.

9.1.7. The graph results should include the calibration values.

10. PRECISION AND BIAS

10.1. The test method is in development. At present, there is no precision and bias statement for this method.

APPENDIX F MEASUREMENT OF WEARING QUALITIES OF ASPHALT EMULSIONS AND AGGREGATE MIXTURE SYSTEMS (PTM 003)

DRAFT Proposed Method of Test for

Measurement of Wearing Qualities of Asphalt Emulsions and Aggregate Mixture Systems

AASHTO Designation: DRAFT Proposed Test Method 003 (PTM 003)

1. SCOPE

1.1. The test method covers measurement of the wearing qualities of slurry seal and micro-surfacing mixture systems under wet abrasion conditions. The method is also suitable for measuring early cohesion of slurry and micro-surfacing mixes cured to different levels by changing cure conditions.

1.2. The test method is applicable to mixes after the formulation of the slurry seal or micro-surfacing has been optimized and, in particular, its set additives and water contents have been adjusted to prepare homogenous flowing consistency.

1.3. The test method is in development.

1.4. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. ASTM D 3910-80a, Practice for Design, Testing, and Construction of Slurry Seal.

2.2. ASTM D 6372, Practice for Design, Testing and Construction of Micro-Surfacing.

2.3. ISSA TB 100, Test Method for Wet Track Abrasion of Slurry Surfaces.

2.4. SCREG Surface Cohesion Test for Slurry Systems, Jean Lefebvre, ISSA 37th Annual Meeting, Mexico, 1999

3. SUMMARY OF METHOD

3.1. Asphalt emulsion, aggregate, setting additives, and water are the components of the mix. The proportions of the components will be derived after optimizing the binder content from previous testing as recommended in the mix design. The mix components, at the prescribed temperature, humidity, compacted/uncompacted and day/night conditions, are cured for specific time periods. After curing, the specimen is placed in a circular pan on the planetary type mechanical mixer. The specimen surface comes in contact with the abrading dual wheel head. The wheels move across the surface in a planetary movement and abrasion occurs for 60 seconds. After the end of abrasion, the specimen debris is washed off. The sample is dried by absorbent paper and this final weight is compared to the original weight before abrasion.

3.2. A loss mass below 100 g is representative of a high cohesion slurry seal or micro-surfacing mix. A loss of mass of 300 g represents an average cohesion. When the loss of mass is close to 600 g, it is expected that the slurry seal or micro-surfacing mix will not resist traffic.

4. SIGNIFICANCE AND USE

4.1. The test method will measure early stage abrasion resistance and also abrasion resistance of fully cured mixtures.

4.2. The test method can quantify the influence of some formulation parameters on setting time and cohesion build up (such as variations of the mix components or the environmental temperature and/or humidity conditions while laying).

4.3. System classification of long-term moisture susceptibility may be determined by the use of varying wet-curing conditions.

4.4. Correlations between laboratory results and field performance will be explored during the development of the test method.

5. APPARATUS

5.1. Planetary type mechanical mixer, such as Hobart C-100, N-50, A-200, or A-120 equipped with a dual wheel abrasion head, quick-clamp mounting plate, and flat bottom metal pan. See Figure 1.
5.1.1. Wheels: 100 mm diameter with 22 mm contact width.
5.1.2. Wheel hardness of 75 and 95 (durometer reading) foot.
5.1.3. Abrasion head should weigh between 1100 g and 1150 g.

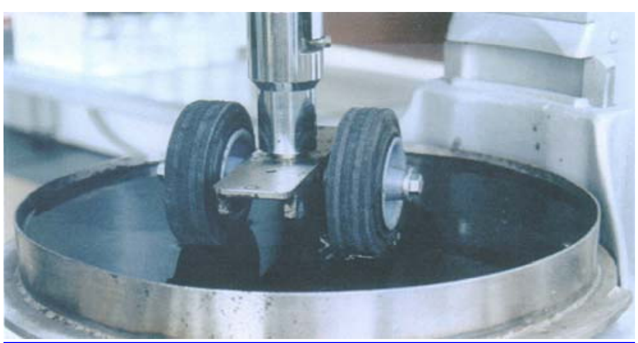

Figure 1. Apparatus 5.1.

5.2. 30-pound saturated roofing felt or other suitable non-absorptive specimen mounting discs, 286 mm in diameter.

5.3. Suitable specimen molds of specified depth (6.35mm is standard) and specified inside diameter: 279 mm for the C-100 and A120 mixers and 254 mm for the N-50 mixer. A raised lip mold is preferred but a flat surface polymethyl methacrylate mold is satisfactory.

5.4. Mold strike-off apparatus such as a 30 to 36 mm window squeegee, 25 mm diameter x 350 mm wooden dowel or a mechanically tracked one-pass squeegee.

5.5. Scales, with capacity of 2000.0 g, accurate to +/- 0.1 g

5.6. Wooden prop block or device to support the pan and mounting plate assembly during the test.

5.7. Suitable rust-resistant mixing containers, spoons

5.8. Constant temperature water bath controlled at specified temperatures.

5.9. Forced air draft ovens and environmental chambers, maintaining specific curing temperatures

5.10. Humidity chamber for curing in high and low humidity conditions.

5.11. 4.7 mm standard ASTM E 11 sieves.

5.12. Means of compacting specimens, if needed.

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6. MATERIALS

6.1. Aggregates--Sample representative portions of aggregates used for slurry seal mix or micro-surfacing mix. Use material of the type, grade, and source proposed for the construction work. Aggregates shall be dried at 60°C to a constant mass and cooled to prescribed test temperatures prior to performing the test.

6.2. Asphalt Emulsion--Use material of the type, grade, and source proposed for the construction work. Asphalt emulsion shall be maintained at prescribed temperature for testing.

6.3. Setting Additives--Use liquid, powdered, or liquid (undiluted or diluted) setting additives where specified from the mix design or through pre-testing.

6.4. Water--Distilled drinking water with a pH between 6.0 and 7.0 shall be used.

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7. PREPARATION OF TEST SPECIMEN

7.1. Maintain test temperatures of the aggregate, emulsion, water, and additives at the prescribed testing temperature.

7.2. The amounts of material components will be quantified as described by the mix design or through determinations from pre-testing using the electric mixing method . In order to minimize delays, all additions of materials, should be pre-determined and pre-weighed prior to starting the stirrer.

7.3. Split or quarter a sufficient amount of the dried aggregate passing a 4.75 mm sieve to obtain 800 g in one quarter (700 g when using the N-50 machine).

7.4. Weigh 800 g of aggregate into a mixing bowl. Using a spoon mix in prescribed amount of dry set additive to the aggregate and mix for 1 minute or until uniformly distributed. Add the predetermined amount of water and mix again for 1 minute or until uniformly distributed. Add the liquid set additive to the mix and mix for 1 minute or until uniformly distributed . Finally, add the predetermined asphalt emulsion and mix for a period not less than 1 minute nor more than 3 minutes.

7.5. Center the opening in the specimen mold on the 286 mm diameter disc of roofing felt. Immediately pour the slurry onto the roofing felt disc.

7.6. Squeegee or screed the slurry level with the top of the mold with a minimum of manipulation. Discard excess material.

7.7. After the prescribed curing conditions, record the weight of the specimen before abrasion.

8. TEST PROCEDURE

8.1. After weighing, place the specimen in a specified constant temperature water bath, if desired.

8.2. Place the specimen in the 330 mm diameter flat bottom pan. Clamp the specimen to the pan and mounting plate by tightening the quick clamps.

8.3 If desired, cover the specimen with 6.35 mm depth of water at a specified temperature.

8.4. Lift the mounting plate until the surface of the specimen comes in contact with the abrading wheel.

8.5. Switch to the low speed of the Hobart machine. Abrade for 60 seconds.

8.6. Rinse the loose debris and dry specimen with an absorbent paper towel. Record the final weight.

9. REPORT

9.1. Report the following information:

9.1.1. Aggregate: percent used, type of aggregate, source and the date received for testing.

9.1.2. Asphalt emulsion: percent used, type of emulsion, source and the date received for testing.

9.1.3. Set additive(s): percent used, type, source, and the date received for testing.

9.1.4. Percent of water used to initially wet the aggregate, if needed.

9.1.5. Curing conditions: temperature, humidity, day/night conditions, aging, and soaking time.

9.1.6. Testing conditions: machine used, running time

9.1.7. Abrasion test result as a total loss of mass.

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10. PRECISION AND BIAS

10.1. This method is in development. At present, there is no precision and bias statement for this method.

APPENDIX G MATERIALS, EQUIPMENT, AND EVALUATION FORMS

Materials Form

Date (MM/DD/YY):	____________			
Observer (Initials):	____________			
Project Location (State/Route/GPS):	____________			
Environmental Zone (Circle):	DNF	DF	WNF	WF
Type of Test Section:	____________			
Original Construction Date ((MM/DD/YY):	____________			

	Quantity (%)	Type	
Polymer Modifier:	______	____________	(Natural Latex/SBR)
Additives:	______	____________	
Water:	______		
Cement/Mineral Filler:	______	____________	

* Type of Test Section (Control, Micro Type 1, Micro Type 2 - Dependant on Phase II Results)

Equipment Form

Date (MM/DD/YY):	____________________			
Observer (Initials):	____________________			
Project Location (State/Route/GPS):	____________________			
Environmental Zone (Circle):	DNF	DF	WNF	WF
Type of Test Section:	____________________			
Original Construction Date (MM/DD/YY):	____________________			
	Type			
Paving Equipment:	____________________			
Spreader Box:	____________________			
Crew Size:	____________________			
Breaking and Curing Rate:	____________________			

* Type of Test Section (Control, Micro Type 1, Micro Type 2 - Dependant on Phase II Results)

Evaluation Form

Date (MM/DD/YY): ____________________

Rater (Initials): ____________________

Project Location (State/Route/GPS): ____________________

Section ID: ____________________

	Distress					
	Low		Medium		High	
Fatigue Cracking (Alligator):						
Block Cracking:						
Edge Cracking:						
Longitudinal Cracking						
Transverse Cracking	Number	Length	Number	Length	Number	Length
Patching:						
Potholes:						
Rutting:						
Shoving:						
Bleeding:						
Polished Aggregate:						
Raveling:						
Water Bleeding/Pumping	Number	Area				

	Comments
Abrasion:	
Delamination:	
Drag Marks:	
Wash Boarding:	
Surface Texture:	
Noise:	dB